



# Makerspaces in Primary School Settings

## Advancing 21st Century and STEM capabilities using 3D Design and 3D Printing

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# Abstract

The *Makerspaces in Primary School Settings* project sought to examine how maker activities using 3D design and 3D printing technology could enhance learning and teaching outcomes. Across the 24 Kindergarten to Year 2 classes that were analysed, students developed a range of 21st century capabilities including creativity, problem solving, critical thinking, inquiry, design thinking, collaboration, autonomy, literacy, numeracy, scientific understanding, digital literacy, communication, reflective learning capabilities and resilience. Analysis of screen recordings for 24 pairs of students revealed substantial levels of design thinking skills, prominently including discovery, interpretation and ideation, but also experimentation and evolution.

Based on screen recordings, teacher journals, teacher questionnaires, student and teacher interviews, and researcher observations, learning and teaching in makerspaces was affected by the balance of explicit instruction to open-ended inquiry, the pedagogical strategies that were used, the types of tasks that were set, the effectiveness of technological resources, the sequencing of tasks, the design of the spaces being used, and students' background knowledge and collaborative capacities. Each of these factors was observed to support or constrain learning, depending on how they were configured.

Maker activities using 3D technology resulted in very high levels of student engagement, as well as increased levels of student confidence (particularly for less capable students). Off-task behaviour was sometimes observed due to factors such as technology being unavailable, students' difficulties working productively in groups, and some of the gamified aspects of the software. There was very strong student demand to complete further lessons involving 3D design and printing, with many students expressing a desire to undertake 3D design activities outside school and in their future careers.

Teachers indicated that the well-structured, pedagogically grounded, hands-on and situated professional learning enabled them to develop a better understanding of makerspaces, how to teach in them, the technical skills required, and 21st century capabilities. The professional learning also significantly increased their confidence to teach in makerspaces. Teachers indicated that to develop their capabilities and effectively teach in makerspaces, they needed reliable technology, collegial support, teaching resources, appropriate makerspaces, and time to build their capabilities and create lessons. In addition, they felt they were assisted by a school culture supportive of exploration and experimentation.

An unanticipated outcome of the study was the extensive teacher transformation that took place. Several teachers indicated that they had shifted to be more collaborative, flexible, and comfortable with technology. Many teachers entered learning partnerships with students, and as a result, students came to see their teachers as models of life-long learning. Some teachers related how these changes had transcended beyond their makerspaces modules – for instance, in the form of more inquiry-based, problem-based, and collaborative units of work. All 24 teachers expressed a desire to utilise 3D design-based makerspaces in their future classes.

# Executive Summary

The *Makerspaces in Primary School Settings* project was a collaboration between the NSW Department of Education, Maker's Empire Pty Ltd and Macquarie University that sought to examine how maker activities using 3D design and printing technology can be pedagogically optimised. There are continual calls from government and industry to advance the STEM capabilities of future generations, from the youngest years of schooling (e.g. Education Council, 2015; Australian Industry Group, 2017). At the same time, the 2017 K-12 New Media Consortium Horizon Report (Freeman, Becker, & Cummins, 2017) identified makerspaces as one of the two main short term technology trends that has potential to transform STEM outcomes in K-12 Education. However, while there is abundant rhetoric about the potential of makerspaces for transforming learning outcomes, there is a paucity of research investigating the pedagogical strategies and issues surrounding learning and teaching in makerspaces, and their impact on the learning process, particularly for younger students, and particularly using a collection of schools and classes (for a review of relevant literature, see Chapter 2 of the main report). This project provided an opportunity to interrogate pedagogical issues surrounding learning and teaching in makerspaces, to work out what is (and is not) effective.

*Makers Empire* produces a 3D design and printing platform that aims to help K-8 educators develop the STEM, design thinking and 21st century capabilities of their students. The *Makers Empire* 3D design and printing platform includes the *Makers Empire 3D* app and teacher platform for class management and access to curriculum. For this project, *Makers Empire* provided their 3D platform to schools, along with a blended professional learning program for participating staff. In total, 27 teachers from three NSW Department of Education schools participated in the project, namely, Carlingford West Public School (n=15), Parramatta East Public School (n=9) and Oatlands Public School (n=3). With responsibility for either Kindergarten (n=12, 44.4%), Year 1 (n=7, 25.9%), Year 2 (n=5, 18.5%) or non-teaching leadership roles (n=3, 11.1%), the teachers who participated in the study ranged in teaching experience from being in their first year of teaching to having taught for over forty years (with an average experience of approximately 11 years). Each class had around 22 students, resulting in approximately 500 K-2 students who used the *Makers Empire 3D* app in the participating classes. Data collection took place between August and November of 2017.

Six research questions drove the inquiry:

- RQ1. What do students learn when undertaking maker activities?
- RQ2. How do maker activities using 3D technology impact on students' design thinking skills?
- RQ3. What supports and constrains learning in maker activities?
- RQ4. How do maker activities using 3D technology influence student motivation, engagement, self-efficacy and future intentions?
- RQ5. How can teacher capacity to embed design thinking processes through maker-based pedagogies be developed through blended professional learning?
- RQ6. How can teachers be best supported to develop their maker pedagogical capabilities?

A collective case study using a mixed methodology was adopted, using nine data sources that included: (1) a pre-professional learning questionnaire; (2) researcher observations of professional learning; (3) a post-professional learning questionnaire; (4) researcher observations of lessons; (5) recordings of student iPad activity and discussions; (6) teacher reflective journals; (7) student focus group interviews; (8) teacher focus group interviews; and (9) a post-implementation questionnaire. Quantitative analysis involved primarily involved the use of descriptive statistics and T-tests. Qualitative data was analysed thematically to derive first and second order themes. Analysis from the multiple data sources was triangulated to enhance reliability of the findings. See Chapter 3 for further details about the methodology and participants.

## Analysis of the Professional Learning Program

The Makers Empire professional learning program consisted of two face-to-face training days (in August and September, 2017) separated by an intervening period of five weeks, during which online support was provided in the form of an *Edmodo* group page with online discussions and weekly webinars. The first workshop covered principles of constructionism and design thinking using a series of hands-on activities, followed by a session covering the use of the *Makers Empire 3D* app. The online professional support included an *Edmodo* course page to promote asynchronous communication between the Makers Empire facilitator and participating teachers, and weekly live web-conferencing sessions using *Zoom*, where the facilitator could present on topics of interest and field questions from teachers. The final face-to-face workshop consisted of a session explaining the operation of the 3D printers being used in the schools, a discussion of teachers' progress with the app and their lesson planning, and a final session where more concrete lesson planning occurred with relation to the NSW curriculum. See Chapter 5 for more details about the professional learning program.

Paired sample T-tests of teachers' responses to the pre- and post- professional learning program questionnaires revealed increases in their confidence to teach in makerspaces from a mean of 3.04 (approximately 'neutral') to 4.44 (between 'mildly agree' and 'agree'), which was a statistically significant result ($t(26)=4.875$, $p=0.000$). Based on clustering according to general, self-identified confidence with technology, the professional learning appeared to be of greatest benefit to teachers identifying as having lower confidence. Of interest was a slight decrease in overall enthusiasm to teach in makerspaces from a pre-professional learning mean of 5.22 to a post-professional learning mean of 4.78. This difference was not statistically significant, $t(26)=1.762$, $p=0.09$, and thus is likely to be within the margins of error or chance, or may possibly be related to the time of term and/or greater teacher awareness of the work they would need to undertake to prepare their modules.

Teachers felt that the professional learning was important because it helped to improve their understanding of what makerspaces were, how to teach in them, the sorts of technical skills they would need, at the same time as it advanced their 21$^{st}$ Century and design thinking capabilities more generally. Teachers appreciated the hands-on and experiential nature of the professional learning program, the technical skills that were covered, and the time that it gave them to collaboratively plan with peers. Suggestions for improvement included providing more time to master the technologies and centring the online professional support around teachers' needs. The main concerns that teachers identified going forward were accessing collegial support, potential technological problems, access to required hardware, how to best support students, and having enough time for planning and implementation. See Chapter 6 for more details about the evaluation of the professional learning program.

## Analysis of the Implemented Makerspaces Units

A wide range of topics were observed across the makerspaces units of work, including designing keyrings, shadow puppets, a habitat for hermit crabs, headphone cable holders, spinning tops, floatable boats, herb markers, playground sculptures, bag tags, and characters for a stop-motion narrative. Researchers' observations of 31 lessons taught by 24 teachers revealed high levels of creativity (71% of lessons), design thinking (64%) and critical thinking (58%). High levels of student engagement were observed in 100% of lessons. Teachers used a mix of online and offline activities, as well as an assortment of activities involving explicit instruction at some times and open-ended inquiry at others. An example of a typical explicit instruction episode is shown in Figure 1 below (Figure 7.1 in the report). An example of students engaging in open-ended inquiry is shown in Figure 2 (Figure 7.2 in the report).

Figure 1 – Teacher modelling using a screenshare of her iPad onto the interactive whiteboard

Figure 2 – Students completing an open-ended task individually and in pairs

Table 1 provides a summary of the sorts of learning and teaching activities that were observed (described in further detail in Chapter 7).

Table 1 – Types of Learning and Teaching Amongst the 31 Observed Lessons (reproduction of Table 7.4 in main report)

| *Domain* | Descriptors | Code | Frequency (n) | Frequency (%) |
|---|---|---|---|---|
| *Student Learning (SL)* | Demonstrated skills | Creativity | 22 | 71% |
| | | Design Thinking | 20 | 64.5% |
| | | Problem Solving | 18 | 58.1% |
| | | Critical Thinking | 15 | 48.4% |
| | | Authentic Learning | 11 | 35.5% |
| | | Inquiry | 5 | 16.1% |
| *Learner Engagement (LE)* | Observed learning behaviours | Engagement | 31 | 100% |
| | | Collaboration | 14 | 45.2% |
| | | Autonomy | 13 | 41.9% |
| *Task Design (TD)* | Task design and types of making | Online (making with technology) | 15 | 48.4% |
| | | Offline (making with physical materials) | 6 | 19.4% |
| | | Hybrid (Online and Offline) | 10 | 32% |
| *Teaching Approaches (TA)* | Pedagogies, instructional methods, and strategies employed | Explicit Instructions | 24 | 77.4% |
| | | Open-Ended Inquiry | 17 | 54.8% |
| | | Problems | 18 | 58.1% |
| | | Team teaching | 4 | 12.9% |
| | | Stations | 4 | 12.9% |
| | | Project Based Learning | 1 | 3.2% |

It appeared that a pedagogical approach involving a balance of explicit instruction and open-ended inquiry resulted in the most effective learning environment, rather than an approach heavily weighted towards one extreme. It also appeared important for teachers to select and establish an authentic problem to provide focus and motivation for the lesson. Makerspaces were observed to involve unique challenges relating to the translation or 'reification' of offline designs into online designs and back again. This was seen to be a critical and relevant point of learning that can result from makerspace-based activities. See Figure 3 for an example (Figure 7.6 in main report).

Analysis of screen recordings from 24 separate episodes of pairs of students working together on the iPads revealed high levels of design thinking. Specifically, across the approximately 16 hours of video analysed, there were 52 instances of 'Discovery', 142 instances of 'Interpretation', 219 instances of 'Ideation', 101 instances of 'Experimentation' and 15 instances of 'Evolution' observed by the research team (see Table 8.5). These were realised through a range of operations in the *Makers Empire 3D* app, including object creation, positioning, resizing, rotating, joining and rendering. High levels of student-to-student dialogue often occurred, with the teacher having the opportunity to circulate around the class and act as facilitator as required. Very high levels of engagement were also observed, but in some instances, this could include off-task behaviour relating to the avatar and gamification aspects of the platform. For a summary of the screen recordings and their analysis see Chapter 8.

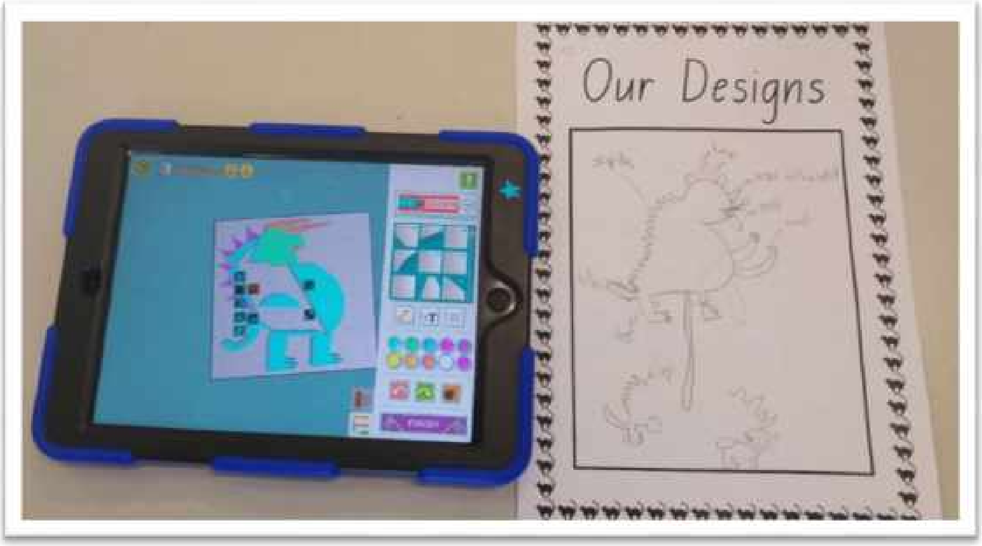


Figure 3 – Student translation of Gruffalo drawing to a digital design

In their reflective journals, teachers documented a range of challenges that they experienced, including finding an appropriate problem, access to equipment, technical difficulties, student misconceptions about what could be 3D printed (such as working robots), the still-emerging background knowledge of some students (for instance, of ratios), students' distraction, and the still-emerging nature of their collaborative skills. At the same time, and often in response to these challenges, teachers identified a range of strategies that supported learning in makerspaces, including explicit instruction, modelling, open-ended inquiry, pair work and group work, class discussion, questioning, scaffolding, reinforcement and revision, and resources such as models, presentation slides, visual cues, and QR codes. For further details about themes emerging from the teacher reflective journals, see Chapter 9.

## Analysis of Participant Summative Reflections

In their focus groups, students were keen to discuss what they had designed using the *Makers Empire 3D* app and were able to identify the influence of the makerspaces activities on their learning. Among the 34 students interviewed, most either explicitly or implicitly articulated how the makerspaces lessons involved creativity and imagination ("you can make anything"), critical thinking and problem solving ("I did the same to reflect it to the other side too… then I add this little thing so we can hold it"), and development of content knowledge through tasks that they saw as relevant to the real world. Many were able to articulate how they had met functional requirements of the design problem they had been given. Students often enjoyed the opportunity to direct their own learning in the makerspaces lessons and saw the lessons in part as an exercise in collaboration. However, some students identified that collaboration problems could occur, for instance if their "group wasn't working as a team". Some students found it challenging to operate the interface at times, such as when interpreting the app interface, or placing and resizing objects, and some students desired more shapes to work with.

Many of the students interviewed were highly positive in their reviews of the *Makers Empire 3D* app, with verbal ratings offered such as "100%" or "11 out of ten". Eight students (23.5%) chose to voluntarily use the app at home for fun, often with members of their family. All students indicated a desire to keep using

3D design and printing in future lessons. There were 32 students (94.1%) who wanted to use 3D design and printing once they left school, for instance as a career ("…build houses so like… maybe people living in the street can have houses for them to get and live in") or for fun ("…like a toy, because I [already] made a toy ball for my dog"). An informal survey of students at one of the participating schools revealed that 292 of 297 students (97%) would like to complete another unit of work involving 3D design using the *Makers Empire 3D* app. For further details about the student focus groups, see Chapter 10.

The 27 teacher responses to the post-implementation questionnaire responses were compared using a seven-point scale from (0) "Strongly Disagree" to (6) "Strongly Agree". Results are graphically represented in Figure 4.

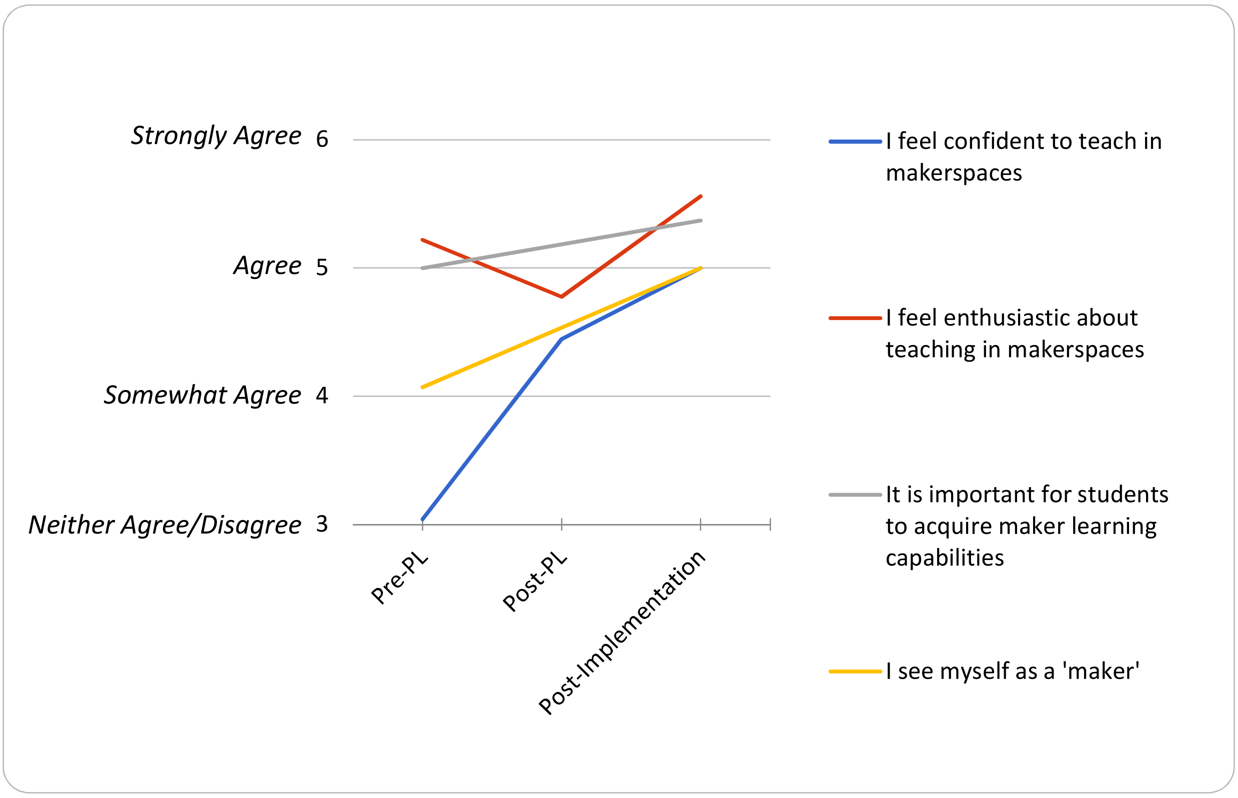


Figure 4 – Likert scale items across all stages of the study

Results indicate significant improvements to teachers' confidence, $t(26)=7.29$, $p=0.000$, and enthusiasm, $t(26)=2.55$, $p=0.017$, to teach in makerspaces at the end of the project. While the increase in their perceived importance of students acquiring maker learning capabilities was not significant, $t(26)=1.91$, $p=0.067$, the high levels of initial importance and sustained levels of post-project importance are notable. Teachers also appeared to undergo a shift in identity, being significantly more likely to identify themselves as makers at the end of the project. Additionally, according to the demographic questions, teachers' general confidence in teaching with technology increased from a mean score of 1.8 (between 'low' and 'medium') in the pre-professional learning questionnaire to a score of 2.4 (between 'medium' and 'high'), which was a highly significant result, $t(26)=5.2$, $p=0.001$. See Chapter 11 for further details about the teacher post-implementation questionnaire.

In the teacher post-implementation focus groups the teachers indicated a range of positive student outcomes emerging from the project, including:

- creativity ("I had lots of girls engaging in building type challenges, and boys drawn to creative, free make tasks");
- collaboration ("It was really good to see them just working in groups, designing it, talking about what features they wanted");
- autonomy ("It was incredible to see what they could figure out just by playing around with the app and then share with their peers, rather than me keeping them all together");
- content knowledge development ("…[the shadow puppet task] really got us deeper into the science side of light");
- critical thinking ("…when we'd printed, and then they had a look at the flaws in their design … and then they went back and changed it [their designs], and I think that part right at the end was really where a lot of the learning took place");
- problem solving ("I haven't given them any help, [and] between themselves, [they have] worked out how to make sure it's [the component] not going to fall off when it gets printed");
- engagement ("…[one of my students] struggles with reading and a lot of things, and when we do anything to do with Makers Empire, his face lights up");
- literacy ("Once they were refining their designs, the language that they used was excellent");
- confidence ("Lower ability kids' confidence improved a lot, and they came up with fantastic, exciting ideas");
- resilience ("The main thing that I loved was that they sort of found problems with their designs and they weren't really intimidated by that anymore");
- reflection ("The main thing my students got from it [the unit of work] is that they just learned to be really good, reflective learners"); and
- excitement ("They were so excited to have the printed object… something that's a physical thing they could use").

Several teachers also pointed out that they appreciated how the makerspaces project enabled them to implement an integrated curriculum, with one teacher commenting that "I really liked how it allowed me to look at learning as a whole, right, not 'this is English, this is Maths'… Really, I could think about in what ways I could make it more meaningful. I could change it and relate it to all the Key Learning Areas". There were also repeated stories of student transformation, for instance, where one of Kindergarten teacher Julia's previously reluctant writers had later become "a shining star".

Teachers identified a range of strategies during the interviews that they felt were important to incorporate into their lessons, in addition to those raised in the reflective journals. These included the explicit integration of a design thinking cycle, a balance of explicit instruction and open-ended exploration, the use of authentic problem-based tasks and real world connections, the use of offline tasks to support online design processes, encouragement of constructive peer feedback, and the provision of adequate time to experiment. One teacher felt that the *Makers Empire* platform was essential for supporting design thinking in her unit of work, commenting that refining designs "is a skill that they may not have had [achieved] without the support of the app". Teachers also utilised strategies to speed up the 3D printing process such as printing multiple designs at smaller scale.

Teachers reiterated several challenges that they experienced during the modules, including technical problems with the 3D printing, the time it took to print objects, their lack of knowledge about 3D printing and the *Makers Empire 3D* app, their students' lack of access to hardware, the limited technical support within the school, and having insufficient time to complete the module of work within an already crowded curriculum. In addition, some Kindergarten teachers felt that manipulating and interpreting the *Makers Empire 3D* app posed literacy and dexterity challenges for their young learners, which prompted them to provide highly explicit instructions at times. Teachers also saw as essential an appropriately-configured learning space for the task at hand, in terms of equipment and flexible furniture. Translating or 'reifying' offline design drafts into online designs and vice versa was viewed as a challenge by some teachers, but also as an opportunity to develop relevant problem solving and digital design skills.

An unanticipated outcome of the study was the self-reported changes in teachers' practice that took place. Several teachers indicated that they had shifted to be more collaborative, flexible, and comfortable with technology. The classroom environment became one where they were in learning partnerships with students, and as a result, students came to see them as models of life-long learning. Some teachers related how these changes had transcended beyond their makerspaces modules into their general teaching, for instance in the form of more inquiry-based, problem-based and flexible learning designs. All of the 24 classroom teachers who participated in the focus group expressed a desire to integrate 3D design-based makerspaces into their future classes. For further details about the teacher focus groups, see Chapter 12.

## Findings

Triangulating the analyses of the nine data sources led to the following findings in response to the research questions.

1. **How do maker activities using 3D technology impact on students' design thinking skills?**

When undertaking makerspace-based activities, students were observed to develop creativity, problem solving skills, critical thinking, inquiry capabilities, design thinking skills, collaborative skills, autonomy, literacy, numeracy, scientific understanding, technological capabilities, communication skills, reflective learning capabilities, and resilience.

2. **How do maker activities using 3D technology impact on students' design thinking skills?**

Maker activities using 3D technologies resulted in students demonstrating extensive design thinking skills in discovery, interpretation, ideation, as well as varying degrees of competence with experimentation and evolution. Students also cultivated the capacity to translate their offline designs into online representations, and developed a range of other 21st century skills as part of the design process.

3. **What supports and constrains learning in maker activities?**

Learning in makerspaces is affected by the balance of explicit instruction to open-ended inquiry, the general pedagogical strategies that are used, the types of tasks that are set, the effectiveness of technological resources that are used, the sequencing of tasks, the design of the spaces being used, students' background knowledge, and their ability to collaborate productively. Each of these factors were observed to support or constrain learning, depending on how they were configured.

**4. How do maker activities using 3D technology influence student motivation, engagement, self-efficacy and future intentions?**

Maker activities using 3D technology resulted in very high levels of learner engagement, as well as marked increases to some students' confidence – particularly those less capable students. Off-task behaviour was sometimes observed to result from unavailability of technology resources, students' developing abilities to work productively in groups, and gamification aspects of the software. There was strong student demand to undertake further lessons involving 3D design and printing, with many students expressing a desire to engage in 3D design activities outside school, and in their future careers.

**5. How can teacher capacity to embed design thinking processes through maker-based pedagogies be developed through blended professional learning?**

Involving face-to-face workshops and online support, the professional learning program led to a significant increase in teacher confidence to teach in makerspaces. Teachers indicated that the well-structured, pedagogically grounded, hands-on and situated approach teachers having a better understanding of makerspaces, how to teach in them, the technical skills required, and 21st century capabilities more generally. Prioritising time to master the technology and repositioning the online professional learning as more responsive to teacher needs are potential strategies going forward.

**6. How can teachers be best supported to develop their maker pedagogical capabilities?**

For teachers to effectively develop their maker pedagogical capabilities, they need to be provided with access to reliable technology, collegial support, teaching resources, appropriate makerspaces, and time to develop their capabilities and lessons. In addition, they are best supported by a school culture that encourages exploration and experimentation. For more detailed explication of each of these findings and the data sources that evidence them, see Chapter 13.

## Future Considerations

As a result of the analysis conducted in this research project and the findings gleaned, the research team proposes:

1. that support be provided to promote makerspaces in schools as an effective and integrated means of developing STEM skills, digital competencies, and 21st Century learning capabilities;
2. that teachers who are implementing makerspaces modules are encouraged to strike a balance between explicit instruction and open-ended inquiry, set authentic tasks that are appropriately problematised, sequence tasks constructively, consider the design of their teaching spaces, attend to students' prerequisite knowledge, and actively guide group work processes;
3. that co-ordinated professional learning opportunities be provided to teachers to improve their knowledge of design-based learning and how makerspaces curriculum can support its development;
4. that the professional learning opportunities provided to teachers is well structured, pedagogically grounded, hands-on and collaborative, incorporating extensive opportunities to explore new technologies and being responsive to individual contexts;

5. that strategies be applied to address potential accessibility and distraction issues associated with the use of the 3D design software by young children;
6. schools take deliberate and comprehensive steps to provide the resources, spaces, and culture that support makerspace-based learning;
7. schools apply strategies to provide teachers with time to design and implement their makerspace-based lessons;
8. schools are encouraged to share and collaborate to build maker expertise amongst staff, engaging parents and other community stakeholders in forming makerspaces communities of practice; and
9. further research to determine effective systems through which Makerspace leadership capabilities can be developed and propagated within and between schools.

## Acknowledgements

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# PART I

# Background to Study

# 1 Introduction

*Chapter 1 explains the motivation and context for this study of how makerspaces in primary school settings can be pedagogically optimised. The two organisations participating in the study are briefly introduced – Makers Empire, a producer of 3D design and printing platform for Kindergarten to Year 8 students, and the New South Wales Department of Education, by virtue of the three participating schools: Carlingford West Public School, Oatlands Public School, and Parramatta East Public School. The rationale for the study is clarified, in light of the national and international push to advance STEM and 21st century learning outcomes from the earliest years of schooling, and the paucity of quality research relating to makerspace-based pedagogy, particularly in the early years. Finally, the research questions that guided the study are introduced.*

## 1.1 About the Study

The *Makerspaces in Primary School Settings* project was a research collaboration between three education-based organisations investigating makerspaces in Kindergarten to Year 2 (K-2) settings. Makers Empire – an Australian-based education technology company behind the development a 3D design and printing platform – provided a blended professional learning program to teachers from three NSW Department of Education primary schools in the Greater Sydney metropolitan area. Participating teachers and their students were also given access to the company's 3D design software (the *Makers Empire 3D* app), which was installed on school-provided iPads and used with newly-purchased 3D printers. Teachers designed and delivered units of work in the *Makers Empire Teacher Dashboard,* integrating both offline maker activities with physical materials and online activities with the available technologies. Throughout the professional learning program, learning implementation, and post-implementation evaluation, a research team from Macquarie University examined teachers' and students' participation and perceptions.

The findings presented in this report aim to elucidate how maker activities using 3D technology can be pedagogically optimised. Part I provides readers with a background to the study that includes an introduction, review of relevant literature and discussion of the research design and methodology used. Part II provides in-depth summaries of findings based on the blended professional learning program in which teachers participated, including pre- and post- questionnaires, and observations of participation in both face-to-face and online components. Part III presents findings from the teaching and learning implementation, including researchers' classroom observations, content analysis of video screen recordings, and analysis of weekly teacher reflective journals. Part IV provides findings from the post-implementation stage of the study, including the student and teacher focus group interviews that the research team conducted following the units of work, and the post-implementation questionnaire delivered at the end of the study. Part V provides a synthesis of findings through a critical discussion of the research questions and evidence-based recommendations for practitioners, researchers and policymakers regarding the design and implementation of makerspaces in schools.

## 1.2 Motivations to develop STEM, 21st century, and digital capabilities

There have been a number of recent reports emphasising the need for students to develop their Science, Technology, Engineering and Mathematics (STEM) capabilities (Australian Industry Group, 2017; Deloitte Access Economics, 2014; Education Council, 2015; Innovation and Science Australia, 2017; Kaspura, 2017; PwC, 2015). In their National STEM School Education Strategy, Australia's Education Council (2015) defined STEM education as follows:

> STEM education is a term used to refer collectively to the teaching of the disciplines within its umbrella – science, technology, engineering and mathematics – and also to a cross- disciplinary approach to teaching that increases student interest in STEM-related fields and improves students' problem solving and critical analysis skills. (p. 5)

Students need to develop STEM capabilities so that in the future, they can solve problems in a range of emerging areas including machine learning, cybersecurity, social media and 3D printing (PwC, 2015). The Australian Industry Group identifies the importance and challenge of learning STEM knowledge and skills through an integrated approach, pointing out that "by mid-late 2016 there was a noticeable shift in the conversations about how to integrate individual STEM subjects into the curriculum, although it seems that for many schools this integration remains a significant challenge" (p. 13). The significance of this challenge has led to calls for the teaching of STEM in Primary schools to be the focus of transformation (Prinsley & Johnston, 2015).

Other capabilities that help people solve problems across a range of STEM areas include active learning, complex problem solving, creative problem solving, critical thinking, design thinking, interpersonal skills, lifelong learning, occupation-specific STEM skills, programming, system analysis and evaluation, time management (Deloitte Acess Economics, 2014). A recent report *Foundation for Young Australians (FYA)* (2016) found that "employers have listed more 21st century skills in their job advertisements… [and] the proportion of job advertisements that demand critical thinking has increased by 158%, creativity by 65%, presentation skills by 25% and team work by 19%" (p. 10). The term "21st century skills" is a commonly accepted term for describing 21st century skills such as creativity, critical thinking, communication, collaboration, while also encompassing core literacy, numeracy and digital skills (see P21, 2009). Similarly, in the 21st century *Fluencies* developed by Crockett (2011), skills such as collaboration and creativity with technology are seen as practices that need to be, like language, developed to the point of fluency in the digital age. Consequently, schools and education systems have been prioritising the development of students' 21st century capabilities through a process of curriculum renewal.

Amongst these 21st century skills, there has been particular international emphasis upon students developing their digital capabilities so that they can fluently solve problems using technology (Broadband Commission for Sustainable Development, 2017; ISTE, 2016; OECD, 2016). In a recent OECD report, the importance of universal digital tools for work readiness is emphasised, conceding that "the 'digital divide' has become a skills gap between the haves and the have-nots... digital skills generate a significant return in terms of employment, income and other social outcomes for those who have them, but set up barriers to better life opportunities for those without" (OECD, 2016, p. 9). Thus, there are a range of national and international motivations to develop students' STEM, 21st century and digital capabilities, with this project responding to all of these motivations.

## 1.3 About the Participating Stakeholders

The two key stakeholders in this project were the New South Wales Department of Education, via their three participating schools, and Makers Empire, an Australian education technology company.

*New South Wales Department of Education Schools*

Carlingford West Public School, Oatlands Public School and Parramatta East Public School are NSW Department of Education schools that participate in a collaborative hub. Their hub school network is designed to lead and disseminate innovation within the school system. All three schools had an executive team that was ready to lead innovation and change, along with staff who volunteered to participate in the project. The campus for each school was equipped with access to the NSW Department of Education Wi-Fi network, and had sets of iPads that could be shared amongst students and classes for the purposes of the study.

*Makers Empire*

Makers Empire is an Australian-based education technology company that helps K-8 educators harness the power of 3D technology to teach STEM concepts, design thinking and 21st century learning skills. *Makers Empire 3D for Schools* is a 3D design and printing platform that comprises the *Makers Empire 3D* app and *Makers Empire Teacher Dashboard* for class management and access to curriculum. Makers Empire also offers a 20-hour *Learning by Design* blended professional learning program that supports teachers to integrate 3D technology using pedagogies that develop and enhance students' critical, creative, design thinking and STEM skills. The *Makers Empire 3D* app is used by hundreds of thousands of students in Australia, America, Asia and Europe every day. Given their common interests in understanding how pedagogically optimise 3D design and printing activities in schools, the two entities partnered together in this research project.

## 1.4 Project Research Questions

Six research questions formed the focus of the study, designed to explore the makerspaces in each of the participating schools. The questions enabled the research team to investigate teachers' development of maker pedagogies, their approaches to learning design, and the impact of the professional learning program on their practice. Moreover, the questions afforded the opportunity to investigate how K-2 learners in the participating schools engaged with newly-introduced maker technologies for 3D design and 3D printing, to identify the learning benefits derived from their participation in both offline and online maker activities, and to reveal the challenges they encountered. Finally, the questions also enabled the research team to examine relevant contextual factors in each school that supported and/or constrained efforts to implement the makerspaces.

The six research questions were:

- RQ1. What do students learn when undertaking maker activities?
- RQ2. How do maker activities using 3D technology impact on students' design thinking skills?
- RQ3. What supports and constrains learning in maker activities?
- RQ4. How do maker activities using 3D technology influence student motivation, engagement, self-efficacy and future intentions?
- RQ5. How can teacher capacity to embed design thinking processes through maker-based pedagogies be developed through a blended professional learning program?
- RQ6. How can teachers be best supported to develop their maker pedagogical capabilities?

The research questions informed the selection of data sources and design of the instruments that were used at varying stages throughout the study (see Chapter 3 Methodology). The findings in Chapter 13 synthesise analyses from across all stages of the project to directly address the research questions.

# 2 Literature Review

*This literature review commences by introducing key policy documents motivating the development of STEM and 21$^{st}$ century learning capabilities. Makerspaces and the maker movement more broadly are defined, including their espoused benefits. Literature relating to 3D design and 3D printing is also briefly reviewed to provide background for the core makerspace technologies that are used in this study. The study is also situated in relation to the NSW K-6 Science and Technology Syllabus as the local curriculum context, noting that similar outcomes are represented in other syllabus documents nationally and internationally. Literature relating to primary school makerspace-based learning is summarised, identifying the limited body of research at the lower-primary level that is in-depth, pedagogically focused, and based on samples of more than one class. Scholarly pedagogical underpinnings of makerspace-based learning and teaching are introduced, in terms of constructivist and constructionist theoretical foundations, design thinking, and learning design more broadly. The few studies that relate to makerspace-based professional learning are also reviewed.*

## 2.1 Makerspaces and the Maker Movement

The recent rise of makerspaces-based learning presents a means for educators to advance STEM and 21st century learning outcomes. In the K-12 context, the 2017 *Horizon Report K-12* (Freeman et al., 2017) observes that makerspaces as a topic has been included in the annual report since 2015, noting the rise of Makerspaces "from compelling phenomenon to global movement" (p. 40). In their discussion of the maker movement, Peppler and Bender (2013) point to "a growing culture of hands-on making, creating, designing, and innovating… [and] a do-it-yourself (or do-it-with-others) mindset that brings together individuals… making nearly anything". (p. 23). Cohen (2017) similarly states that the maker movement is "is characterized by people who engage in the construction, deconstruction, and reconstruction of physical artefacts, and who share both the process of making and their physical products with the broader community of makers" (p. 6). Activities associated with the maker movement generally involve the integration of digital technologies into practices of designing and constructing physical, and sometimes virtual, objects (Peppler, Halverson, & Kafai, 2016). According to Martin (2015), these activities can be distinguished from traditional arts-and-crafts by the way in which digital technologies are used to produce artefacts and facilitate an ethos of open-source sharing.

Definitions of makerspaces in the literature tend to focus on the role of the *space* as an enabler of learning – or, as Kurti (2014) emphasises, "the ideal space for maker education" (p. 8). For example, Sheridan, et. al. (2014) define makerspaces as "informal sites for creative production in art, science, and engineering where people of all ages blend digital and physical technologies to explore ideas, learn technical skills, and create new products" (p. 505). Others such as Oliver (2016a) similarly regard makerspaces as "a physical space with shared resources to pursue technical projects of personal interest with the support of a maker community" (p. 160). Bowler and Champagne (2016) prefer to emphasise the learning that can occur within the space, defining the term as "a physical place where informal, collaborative learning can happen through hands-on creation, using any combination of technology, industrial arts, and fine arts" (p. 117). Similarly, Freeman, Becker and Cummins (2017) contend that building dedicated makerspaces "can be perceived as secondary to the true spirit of this trend — integrating the maker mindset into the formal curriculum to spur real-world learning" (p. 40). Giannakos, Divitini and Iversen (2017) believe that that the spaces enable greater expression, with "making to invent new forms of expressiveness and utilize technology to support twenty-first century education" (p. 80).

In a seminal review of makerspaces, Vossoughi and Bevan (2014) analyse empirical findings and abstract three key observed benefits of maker-based learning activities. The first benefit is greater participation in science environments, where students were able to investigate real world, scientific phenomena and create different representations to show their understanding. Related to this, the review further finds that makerspaces support academic and disciplinary development by encouraging the integration of STEM disciplines in an authentic way. The third main benefit derived from the literature is the creation of communities of learners – and this included both teachers and students – who can learn in partnership through the sharing of problem solving strategies, design ideas, and artefacts.

In a related position paper, Martin (2015) explores key elements of the maker movement, and associated research needs, that he believes are necessary to understanding its promise for education. The author cites seven key reasons as to why making is a valuable activity, including that it:

1. can align with curriculum demands of schools;
2. gives students access to sophisticated building and thinking;

3. encourages a culture of creativity;
4. fosters playfulness through tolerance of errors;
5. advocates a growth mindset;
6. provides learner choice; and
7. intrinsically incorporates learning through community.

Finally, building on this earlier work, Bevan (2017) identifies the capacity of well-designed makerspaces to promote integrated STEM learning:

> STEM-Rich Making is by its nature interdisciplinary. Entailing practices of design, engineering, and sometimes mathematics, it positions science concepts and phenomena – such as electrical circuitry, force and motion, energy transfer, or cause and effect – as the central tools or materials necessary to the Making processes (p. 76).

## 2.2 Theoretical foundations of makerspace-based learning

The learning theory that is most often invoked to explain learning in makerspaces is constructionism. Constructionists hold that learning is most effective when it occurs through participation, and when the learning process embodies learner-led inquiry, creativity and making. The leading exponent of the theory, Papert (1986) states that constructionism "takes a view of learning as a reconstruction rather than as a transmission of knowledge… Then we extend the idea of manipulative materials to the idea that learning is most effective when part of an activity the learner experiences as constructing a meaningful product" (p. 2). As such, constructionist thinking draws on constructivism, an older and widely-accepted learning theory that considers how learners construct knowledge through the interaction of their experience and ideas. The term "constructivism" comes directly from Jean Piaget, though a wide number of other thinkers have contributed to the underlying ideals of constructivist learning. As Bevan (2017) notes, "as an educational practice, Making has deep roots in the pedagogies advanced by Fröbel, Dewey, Montessori, and others who have argued for the centrality of materials-based investigations for motivating and advancing student learning" (p. 75). '

In this context, the theoretical basis for the social interaction that some regard as necessary in makerspaces has been articulated as socio-constructivism, where learners learn through scaffolded collaboration with their teacher and peers. Like constructivism, socio-constructivist ideals are broadly attributed to several theorists who further developed their constructivist pedagogies to incorporate social interaction, though Lev Vygotsky is often regarded as the originator of the theory. Socio-constructivism builds on constructivism by emphasising socially-oriented constructivist viewpoints, or "neo-Piagetian" perspectives (Doise, Mugny, & Saint James-Emler, 1984). This theory has since been widely recognised as a basis for exploring knowledge building through collaboration. For Vygotsky, learning occurs on both inter-psychological and intra-psychological planes (Holton & Clarke, 2006). Originally conceived as the Zone of Proximal Development, the difference between the actual developmental level and the level of potential development was explored through "adult guidance or in collaboration with more capable peers" (Vygotsky, 1978, p. 86). Further, in arguing that "what the child is able to do in collaboration today, [she/]he will be able to do independently tomorrow" (p. 287), Vygotsky recognises the value of interaction as a tool for constructing knowledge. As such, socio-constructivist learning often informs the theoretical frameworks of contemporary makerspaces research because making is conceived as a fundamentally social activity and one that draws on interaction and effective collaboration (Dousay, 2017).

Often regarded as experiential, inquiry-oriented and problem-based, learning in makerspaces also has a theoretical basis in pragmatist epistemology, and the educational theories of John Dewey in particular, for whom learning is grounded in activity and experience. Dewey's notion of experience is "broadly conceived… [and] more than simply a matter of direct participation in events" (Rodgers, 2002, p. 846). Dewey sees the development of human knowledge is an adaptive response to the environment, arguing that learning "cannot take place by direct conveyance of beliefs, emotions and knowledge… it takes place through the intermediary of the environment" (1916, p. 12). In many ways, Dewey's idealised form of learning is problem-solving through free, learner-directed inquiry, which he sees as "the self-controlled or directed transformation of an indeterminate situation into one that is so determinate in its constituent distinctions and relations as to convert the elements of the original situation into a unified whole" (1938, p. 108). As Rodgers points out, reflection plays a crucial role in pragmatist epistemology and "needs to happen in a community, in interaction with others" (2002, p. 845). Thus, the pragmatist emphases on experience, self-determination, social tools, and the dialectical relationship between self and the environment are consistent with maker-based learning. Moreover Dewey's "Long Term Project" – often seen as the theoretical basis of contemporary Project-Based Learning (Buck Institute for Education, 2017) – is arguably well aligned with the focus on sustained creativity, problem solving and critical thinking that many makerspaces idealise.

## 2.3 3D Design and 3D Printing

3D design and 3D printing are two areas that commonly intersect with makerspaces, very often featuring as the primary areas of focus in empirical studies. The ability to design and print objects using affordable software and hardware is recognised as a powerful technology combination for authentic, situated learning (Canessa, Fonda, Zennaro, & Deadline, 2013). Others regard the combination of 3D design and printing tools as an opportunity to draw on design principles and ideas for inspiration, and create artefacts that potentially solve larger problems – in the words of Kostakis, Niaros and Giotitsas (2015), "the ability to design globally but produce locally" (p. 127). Eisenberg (2013) stresses the value of students being able to design objects that are personally meaningful, such as construction kits, party ornaments, model railroad scenery, dollhouse furniture and customised souvenirs. Focusing on future potential for 3D printing, the author further surmises that "it is possible to venture still more futuristic scenarios, in which children have the tools and materials with which to create or personalize their own furniture, musical instruments, or sports equipment" (p. 8).

Elsewhere, there is substantial focus on the real-world applicability of 3D-printed objects. For example, in a study by Jafri, Aljuhani and Ali (2017), 3D-printing could be used to support tactile shape perception and spatial awareness for visually impaired students, while a similar study by Kostakis, Niaros and Giotitsas (2015) showed that students could learn about, and design, objects that supported braille for visually-impaired students. While focusing on education, these two studies draw attention to the expanding body of research on the use of 3D printing in the medical community, where it is used for any number of areas such as drug delivery, insulin level recording, simulated organs, and many related areas. In other social contexts, there is some attention on using 3D printing to tackle perennial problems such as homelessness by providing a vehicle for affordable housing, or production issues like making cheap clothing at a local level. Popular 3D printing websites and videos reveal how students are tapping into these real world uses, such as the story of Will, a primary-aged student who successfully designed and brought to market a diabetes test strip remover and disposal unit (HACT Live, 2015).

## 2.4 The curriculum context

In Australia, the last decade has involved the sustained efforts of educational jurisdictions in every state and territory working towards a national curriculum. At its heart, the efforts to nationalise the curriculum reflect calls for education reform to more fully address global citizenship and sustainability while also acknowledging that, in real terms, more students need to become “creative and productive users of technology, especially ICT, as a foundation for success in *all* learning areas” (MCEETYA, 2008, p. 8, our emphasis). At the same time, the Australian Industry Group (2017) report proposes that “many teachers still had questions about how STEM subjects can be integrated within the constraints of school timetables and rigid structures that pervade… and the school curriculum is still largely structured to deliver education in single subject areas and this was constantly raised by teachers as a barrier” (p. 13).

However, the push for development of integrated knowledge and skills needed for global citizenship and sustainability is indeed embodied in recent curriculum changes such as New South Wales’ *Science and Technology K-6 Syllabus* (NESA, 2018). With a focus on interdisciplinarity and inquiry, the syllabus emphasises design, system, computational and scientific forms of thinking as technical for solving complex and authentic problems. The syllabus also encourages students to “to embrace new concepts and the unexpected, and to learn through trialling, testing and refining ideas”, as well as “to question and seek solutions to problems through collaboration, investigation, critical thinking and creative problem-solving” (p. 12). The syllabus specifies that by the end of Stage 1, students should be able to “generate and develop design ideas and solutions that they communicate with labelled drawings and models and through the use of digital technologies where appropriate... [and] provide explanations about what they have done and evaluate their ideas using predetermined criteria” (p. 20). Throughout the presentation of syllabus objectives, outcomes and content, inquiry questioning serves as the basis for teachers to program teaching, learning and assessment focusing on real world issues such as sustainability, and the environmental impact of built systems.

While localised to the New South Wales state context, the *K-6 Science and Technology* syllabus reflects the national and international themes of curriculum as a driver for educational change, and specifically the development of enterprise and technical skills through the adoption of makerspaces. Nationally, the syllabus draws ideas from the *Design and Technologies F-10 Syllabus* (Australian Curriculum and Reporting Authority, 2014), which includes a specific focus on the early years and emphasises engineering principles, complex design solutions, two- and three-dimensional modelling and graphical representation. Internationally, the Common Core movement in the United States stipulates similar curriculum content, which some believe is prompting the adoption of makerspaces (see, for example, Del Guidice & Luna, 2013). Others see the knowledge and skills involved in maker-based learning as applicable to localised curriculum areas of need, such as Citizen Science initiatives in the UK and Europe (L. Johnson et al., 2014), understanding first peoples in Canada (Harron & Hughes, 2018), or as a vehicle for future-focused learning in New Zealand (Bolstad, 2015).

## 2.5 Research into Makerspaces in Primary School Settings

Searches of the literature revealed very limited empirical research of makerspaces in the K-6 context, with a paucity of research in the K-2 years. However, several researchers discuss why this may be the case. In the New Zealand context, for example, Bolstad (2015) believes that makerspaces “are still relatively marginal in primary schools, and if these opportunities are present, they are generally run by one or a few teachers, and not something that all students have opportunities to be involved in" (p. 21). The author hypothesises that "activities such as student gaming and coding clubs or makerspaces are not viewed as being especially relevant or important in many schools, or that schools simply have other priorities when it comes to curricular and co-curricular activities" (p. 22).

Among the small number of studies in the K-6 context, findings are encouraging. For example, in one study, Smith and Smith (2016) explore how fourth grade students create projects to illustrate the transfer and transformation of energy, finding that students had "novel, playful and sometimes whimsical ideas [that] show how creativity can flourish when given the chance" (p. 33), and that "working with unfamiliar materials in novel ways provides authentic experiences for students to deepen their understanding of energy and energy transfer" (p. 36). Similarly, in a study of primary-aged children, Chu, Quek, Bhangaonkar, Ging and Sridharamurthy (2015) contend that "making can support the formation of the maker mindset in children", further arguing that "instilling of a self-identity as being a Maker in a child is at least as important at the critical development period of age 8–11 as the transmission of knowledge" (p. 18).

Other studies focus on the use of democratic spaces open to the public, including younger learners. In particular, several studies have explored the use of makerspaces in school libraries and public libraries (Bowler & Champagne, 2016; Wang, Wang, Wilson, & Ahmed, 2016; Yu, 2016). As Wang, Wang, Wilson and Ahmed (2016) observe, "once aware of the characteristics of the makerspace, it is easy to see the link between a library and a makerspace… In the age of print, a library was perceived as a repository of information and knowledge. Today, the role of the library is changing because of the digital revolution" (p. 3). Bowler and Champagne (2016) believe that well-designed makerspaces in libraries can enable a "shift in users' experience from one of passive consumption to another of active production" (p. 118).

Papavlasopoulou, Giannakos and Jaccheri (2017) have systematically reviewed recent empirical research on the use of makerspaces, and, as part of that review, catalogued the learning context examined in the studies that are outlined. Importantly, their findings indicate that makerspaces are often examined across a wide age range that includes both primary-aged and secondary-aged students. Critically, though, these findings show a lack of attention to students younger than Grade 3, with most of the studies focused on upper-primary, secondary and tertiary contexts. Conceding that they did not find many studies focusing on ages earlier than 11 years, the authors call for further research that might show how younger learners can benefit from learning in makerspaces. The lack of research surrounding makerspaces in primary schools and calls from researchers provides impetus for further investigation, particularly in the younger years.

## 2.6 Makerspaces and Design Thinking

Thinking skills that pertain to the design process are often generically referred to as "design thinking" (for clarity, lower case), a concept that has solid traction in research both past (See, for example, Buchanan, 1992) and present (See, for example, Filatro, Cavalcanti, & Muckenberger, 2017). Often relating to approaches to design in industry, educators may draw on principles, cases and strategies for supporting the design process. The concept of design thinking is also now embedded in the New South Wales *K-6 Science and Technology Syllabus* (NESA, 2018). Like much of the research literature, the syllabus defines the concept broadly, but makes clear reference to authentic learning as an ideal context for design thinking, and reference to the nature of the design as a solution to a need, problem or issue:

> Design thinking is a process where a need or opportunity is identified, and a design solution is developed. The consideration of economic, environmental and social impacts that result from designed solutions are core to design thinking. Design thinking methods can be used when trying to understand a problem, generate ideas and refine a design based on evaluation and testing" (p. 35).

As an instructional model, "Design Thinking" (for clarity, title case) is widely used in education. Several models exist, each with slightly different emphases and design stages. Based on a review of the grey literature, Table 2.1 outlines seven of the most popular models used in education, and the design activities that reflect early-, mid- and late-stage design. Common themes that run through the models include exploration and interpretation in the early stages, generation of ideas in the mid stages, and testing, evaluating and evolving in the latter stages.

Table 2.1 – Design Activities of Popular Design Thinking Models Used in Education

| | **Early** | | **Mid** | | **Late** | | |
|---|---|---|---|---|---|---|---|
| ***Model/Stage*** | | | | | | | |
| ***Cooper Hewitt***<br>*(Hewitt, 2011)* | Identify | Investigate | Frame/ reframe | Generate | Develop | Evaluate | Re-evaluate |
| ***d.School***<br>*(Hasso Plattner Institute of Design, 2017)* | Empathise | Define | Ideate | | Prototype | Test | |
| ***Design Minds***<br>*(State Library of Queensland, 2017)* | Inquire | Reflect | Ideate | Reflect | Implement | Reflect | |
| ***IDEO***<br>*(Fierst, Diefenthaler, & Diefenthaler, 2011)* | Discovery | Interpretation | Ideation | Experimentation | Evolution | | |
| ***IDESiGN***<br>*(Burnette, 2005)* | Intending | Defining | Exploring | Suggesting | Innovating | Goal-setting | Knowing |
| ***NoTosh***<br>*(McIntosh, 2018)* | Immersion | Synthesis | Ideation | | Prototyping | Feedback | |
| *Open Colleges (Briggs, 2013)* | Define the Problem | | Consider multiple options | Refine selected direction | Execute the best plan of action | | |

Both the concept of design thinking and various models of Design Thinking can inform learning and teaching in makerspaces. The design thinking research literature suggests that design thinking skills can be well-aligned with makerspaces. For example, Freeman et. al. (2017) note that design thinking encourages “the notion that failure is an essential part of learning, [which] is of-cited but is not always seamlessly ingrained in school culture”, while asserting that “makerspaces champion the process of experimentation and iteration; students design and build, making continuous improvements to prototypes as they learn what works — and what does not” (p. 40). Swanson and Collins (2018) also emphasise the importance of failure in design-oriented learning, stressing that that failure plays “a productive role in the creative knowledge-construction process” (p. 9). The IDEO model (Fierst et al., 2011) is particularly helpful in providing teachers with a detailed handbook that includes scaffolds, stimulus, first-hand accounts and expert advice.

## 2.7 Makerspaces and Learning Design

Learning design takes several principles and practices from the field of design thinking and focuses on the role of the *teacher as designer*. Central to learning design is the design phase, which Bower (2017) contends “is where educators draw together their technological, pedagogical, content, and contextual knowledge to create synergistic solutions to educational problems” (p. 122). Often regarded a balance between art and science, learning design “uses what has gone before as a platform or inspiration for what it creates”(Laurillard, 2013, p. 1). During the design phase, Sharpe and Beetham (2013) argue that educators “arrive at a plan or structure or designed artefact for a learning situation or setting” and believe that the objects of the design process may variously include learning resources, the environment, tools and equipment, learning activities, and/or the learning program or curriculum (p. 8).

These views of learning design underscore the importance of teacher knowledge, particularly with respect to the Technological, Pedagogical and Content Knowledge (TPaCK) framework. The originators of the framework, Mishra and Koehler (2006) argue that teacher knowledge can be understood and measured across the three domains of technology, pedagogy and discipline content. However, the authors argue that properly understanding these forms of knowledge requires a nuanced examination of “the complex roles of, and interplay among, three main components of learning environments” p. 1017). In this respect, the framework identifies seven forms of teacher knowledge that are applicable to learning design, especially technology-enabled learning. In addition to the first-order knowledge constructs of technology, pedagogy and content, there are three second-order constructs that include technological pedagogical knowledge (TPK), pedagogical content knowledge (PCK) and technological content knowledge (TCK), as well as the third order construct of technological, pedagogical content knowledge (TPCK). Ongoing efforts to measure teacher knowledge in relation to one or more of these constructs underscore the importance of teacher knowledge as a predictor of successful learning design.

Perhaps due to its applicability to a wide range of areas related to learning outcomes and the learning environment, and given its focus on the role, knowledge and skills of the teacher, learning design often appears as a related theme in empirical research on the use of makerspaces. For example, drawing on the principles of constructionism, Brenan’s (2017) study of makerspaces in one teacher education program finds that “learning is most powerful when people, whether children or adults, have opportunities to create, to enjoy freedom, to engage in interactions with others, and to cultivate a love for learning” (p. 9). Similarly, in a study of preservice teachers’ design activities, Hosseini (2015) finds that providing opportunities for constructionist learning through maker activities enhances teachers’ TPaCK knowledge across all domains, particularly highlighting the role of maker-based collaboration in knowledge building. Conversely, Tsai and Chai (2012) find that a lack of design thinking skills represents a “third order barrier” beyond basic access to technology and appropriate beliefs, which Harron and Hughes (2018) further believe is detrimental to the success of maker-based learning.

## 2.8 Makerspaces and Professional Learning

Finally, professional learning in and with makerspaces represents a critical area of focus in the literature, with arguably more questions than answers. Bound up with the need for quality professional learning in the Australian educational context are renewed calls for STEM-related skills development, such as the Australian Industry Group (2017) stressing the need for a focus on how teachers "integrate digital technologies into a STEM-based curriculum" (p. 4). This echoes similar sentiment internationally (see, for example, Honey, Pearson, & Schweingruber, 2014) and reflects much of the policy and curriculum push for STEM skills in many K-12 contexts while tacitly reinforcing the view that teachers' STEM knowledge is not at a level where it needs to be.

However, like teaching and learning generally, professional learning has evolved considerably in recent years beyond simple knowledge transmission. Perhaps most importantly, the rise of web-enabled tools for learning has further eroded many of the culturally-embedded assumptions that have shaped teachers' beliefs. For example, Huber's (2010) discussion of the use of Web 2.0 tools by contemporary educators highlights what the author sees as the pressing need to challenge ongoing traditional beliefs such as "passing information on is enough", "insight must come from outside formal training" and "planning means learning" (p. 42). As Huber elaborates:

> Each of these false assumptions takes hold because of a reliance on traditional models for professional development. The school goes through the motions of professional learning, but its approach is based more on the illusion of collaboration than on substantive, ongoing, sustained conversation (p. 42).

The assumption that information transmission is sufficient for sustained teacher professional learning has been challenged by the wealth of technology-informed research that highlights the limitations of this approach and offers a myriad of ways to learn through application, experience and interaction. At the same time, Gibson and Brooks (2012) suggest that while research on teacher professional development (PD) "highlights the characteristics of effective traditional PD over the last 20 years, we need to update the approach relative to the changing realities and specifically the digital affordances of our time" (p. 1).

As Hargreaves (2000) points out, "professional development is usually most effective when it is not delivered by extraneous experts in off-site locations, but when it is embedded in the life and work of the school, when it actively secures the principal's or head teacher's support and involvement" (p. 165). In terms of maker-based professional learning, Oliver (2016b) strongly reinforces the need for "professional learning for long-term change", stipulating that "rather than a one-time workshop, educators [can] continuously build skills, practise facilitation, and develop an understanding of when and how students collaborate" (p. 214). Harron and Hughes (2018) advocate "giving teachers more time to explore materials with lesson development support through further professional development, curriculum specialists, or with other educators" (p. 12), while Bowler (2014) suggests that key school educators can be exposed to design thinking in professional learning, thereby becoming maker leaders in the school culture.

## 2.9 Literature Review: Summary and Concluding Remarks

This review of makerspaces research and related topics was intended to be thematic rather than systematic, or exhaustive, in nature. The research questions were used to guide the themes that the research team selected for the review, with themes that included learning benefits of makerspaces, supports and constraints when teaching in makerspaces, the development and application of design thinking skills, maker pedagogies, and the efficacy of professional learning initiatives. Reviewing the literature in relation to these themes helped to identify relevant educational theory, empirical research, current policy and curriculum change informing the maker movement, as well as any findings that might support, guide, clarify or strengthen the focus of the present study.

Findings encouragingly point to the importance of policy and curriculum as drivers of change, the growing popularity and momentum of the maker movement and the untapped potential of well-designed maker-based learning tasks and environments. These findings stand alongside the perceived problems with teachers' STEM skills, the lack of exposure to design thinking as a framework for learning design, and the relatively limited bodies of empirical research in the use of makerspaces in primary school settings, and in educational applications of 3D design and 3D printing. All these concerns feed into the question of how best to prepare primary school teachers to lead their schools in maker-based learning, given the obvious limitations of many one-day training courses that arguably do not position or value teachers as designers of learning.

# 3 Methodology

*In Chapter 3, the rationale for the mixed methodological approach is described, in terms of enabling determination of key educational effects in makerspaces as well as the reasons for them. The nine data sources are briefly described, namely the pre-professional learning teacher questionnaire, researcher observations of professional learning, the post-professional learning teacher questionnaire, researcher observations of lessons, audio-visual screen recordings of student iPad activity, teachers' reflective journals, student focus group interviews, teacher focus group interviews, and the post-implementation questionnaire. Each of these data sources is related to their corresponding research questions, noting that specific details about instrumentation and data collection for each source are explained in the corresponding chapters. The participating teachers and their backgrounds are also described.*

## 3.1 Research Design

*Makerspaces in Primary School settings* was a collective case study utilising quantitative and qualitative instrumentation – an approach often referred to as mixed methodologies. Johnson and Christensen (2014) regard this approach as adhering to the philosophy of pragmatism. As they explain with reference to mixed methodologies, “the pragmatist researcher carefully thinks about the perspectives provided by qualitative and quantitative research, and then he or she constructs a combined or mixed approach to address the research question or questions” (p. 648). In this respect, mixed methods research often seeks to overcome the limitations of research that is purely quantitative or qualitative. As other well-known researchers such as Yin (2006) argue, “once freed from the quantitative-qualitative dichotomy, the relevance and reality of a broad variety of “mixes” emerges... [that] recognizes the true diversity of the research methods used in education” (p. 42). In this study, mixed methodologies enabled the research team to triangulate findings across datasets, often using quantitative methods to profile participants and qualitative methods to more deeply understand phenomena. As such, a wide range of quantitative and qualitative data points were drawn from both teacher and student participation. The research team examined students’ participation in classes, and teachers’ participation through the professional learning program, teaching and learning implementation and post-implementation evaluation.

An overview of the data sources and corresponding analytic techniques are provided in this chapter. The specific details surrounding the ways in which analytic techniques have been applied to individual data sources is explained in subsequent chapters, to facilitate easier interpretation through contiguity.

## 3.2 Data Sources

A pre-professional learning online questionnaire was delivered to teachers prior to commencing the program, helping to establish baseline data in relation to their prior knowledge, experience and beliefs about teaching in makerspaces. During the program, researchers observed teachers’ participation in the professional learning activities that occurred in two face-to-face training days and via an online Edmodo page with accompanying weekly webinars via Adobe Connect. At the end of the program, a post-professional learning questionnaire measured changes to their knowledge and beliefs.

During the teaching and learning implementation period, the research team coordinated visits to, and observations of, students and teachers in each of the participating classes. During these visits, artefacts such as work samples and final design solutions provided important reference points for exploring cognitive engagement and the efficacy of learning design and maker pedagogies. Video screen recordings of a subset of these students were also captured at this time and revealed how they engaged with the 3D design software provided by Makers Empire. Also during the teaching and learning implementation, teachers were asked to record weekly written reflections on their makerspaces lessons that were privately shared with the research team. In the post-implementation evaluation period, researchers interviewed teachers and students in focus group settings to understand their experiences, and to identify successful project outcomes and stumbling blocks. A final online questionnaire was delivered to teachers at the very end of the project, again to measure changes to their knowledge and believes, and as a final point for evaluating their involvement in the study. Table 3.1 outlines the instrument types used in the study and indicates which types were used to address each of the six research questions.

Table 3.1 – Research Questions and Instrument Types Used

| ***Research Question / Data Source*** | **Pre-Professional Learning Questionnaire** | **Professional Learning Observations** | **Post-Professional Learning Questionnaire** | **Lesson Observations** | **Video Screen Recordings** | **Teacher Reflective Journals** | **Student Focus Groups** | **Post-Implementation Questionnaire** | **Teacher Focus Groups** |
|---|---|---|---|---|---|---|---|---|---|
| *RQ1. What do students learn when undertaking maker activities?* | | | | ✓ | ✓ | ✓ | ✓ | | ✓ |
| *RQ2. How do maker activities using 3D technology impact on students' design thinking skills?* | | | | ✓ | ✓ | | ✓ | | |
| *RQ3. What supports and constrains learning in maker activities?* | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| *RQ4. How do maker activities using 3D technology influence student motivation, engagement, self-efficacy and future intentions?* | | | | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| *RQ5. How can teacher capacity to embed design thinking processes through maker-based pedagogies be developed through a blended professional learning program?* | ✓ | ✓ | ✓ | ✓ | | | | ✓ | ✓ |
| *RQ6. How can teachers be best supported to develop their maker pedagogical capabilities?* | ✓ | ✓ | ✓ | | | ✓ | | ✓ | ✓ |

## 3.3 Data Analysis

According to Johnson and Christensen (2014), most mixed methods analysis draws on dialectical pragmatism, which involves "back-and-forth listening and synthesis of multiple perspectives" (p. 648).

Quantitative analysis mainly involved generation of descriptive statistics of quantitative variables in each of the questionnaires, for interpretive purposes. All questionnaire data was collected using the Qualtrics online survey system. Differences within and between groups on variables of interest were also examined using T-tests and ANOVA. The quantitative analysis was principally conducted using the *Statistical Package for the Social Sciences* (SPSS), Version 24. A significance level of 5% was applied to all statistical tests.

Qualitative analysis was principally undertaken with *QSR NVivo*, Version 11. In all cases, qualitative data were explored inductively, a process that whereby category systems and codes are generated by directly examining each dataset, rather than generated *a priori* (that is, prior to examining each dataset), which is considered "the most common approach used by qualitative researchers… because of the inductive nature of most qualitative research" (B. Johnson & Christensen, 2014, p. 781). Where possible, the research team used emic terms – that is, terms used by the participants themselves. The inductive approach led to different category systems and coding for each of the qualitative datasets analysed. This approach promoted high fidelity to each data set. Where possible, enumeration of qualitative data (that is, the process of quantifying data) was undertaken by outlining the frequency of codes, and in some cases through word counts to help characterise the data sets. Table 3.2 outlines the analysis strategies applied to different data sets. Each of these strategies is further explained in the relevant sections.

Table 3.2 – Analysis Strategies Used in this Report

| ***Strategy*** | **Instrumentation** | **Purpose** |
|---|---|---|
| *Descriptive Statistics* | Online Questionnaires | To describe all quantitative data using commonly-accepted indicators like mean, standard deviation, skewness, histograms, and pie charts |
| *T-Tests and ANOVA* | Online Questionnaires | To explore significant differences between pre- and post- measures, typically in confidence and enthusiasm with makerspaces, and maker identity |
| *Coding* | All qualitative data | To identify and label common themes in the data |
| *Category System* | All qualitative data | To structure the codes using first-order themes (for example, "learning outcomes") and second-order themes (for example, "critical thinking") |
| *Word Frequencies* | Video Screen Recordings | To identify frequently occurring words (including synonyms and stems) in spoken dialogue |

## 3.4 Participant Demographics and Background

Information about participant background and demographic profile was collected prior to commencement of the project via the pre-professional learning questionnaire conducted in the second week of August 2017. The complete questionnaire is provided in Appendix 1. All 27 teachers involved in the study agreed to complete the questionnaire. Twenty-six teachers (96.3%) identified as female and one teacher (3.7%) identified as male. There were 12 Kindergarten teachers (44.4%), seven Year 1 teachers (25.9%), five Year 2 teachers (18.5%) and three teachers with non-teaching leadership roles (11.1%). The K-2 teachers involved in the study each had classes of approximately 22 students.

The distribution of teachers' experience shown in Figure 3.1 indicates that the majority (n=17, 63%) of teachers were within the first ten years of their teaching career. This was further explained by the variance from the mean (M=11, SD=10.5), with the small number of relatively experienced teachers having positively skewed the distribution.

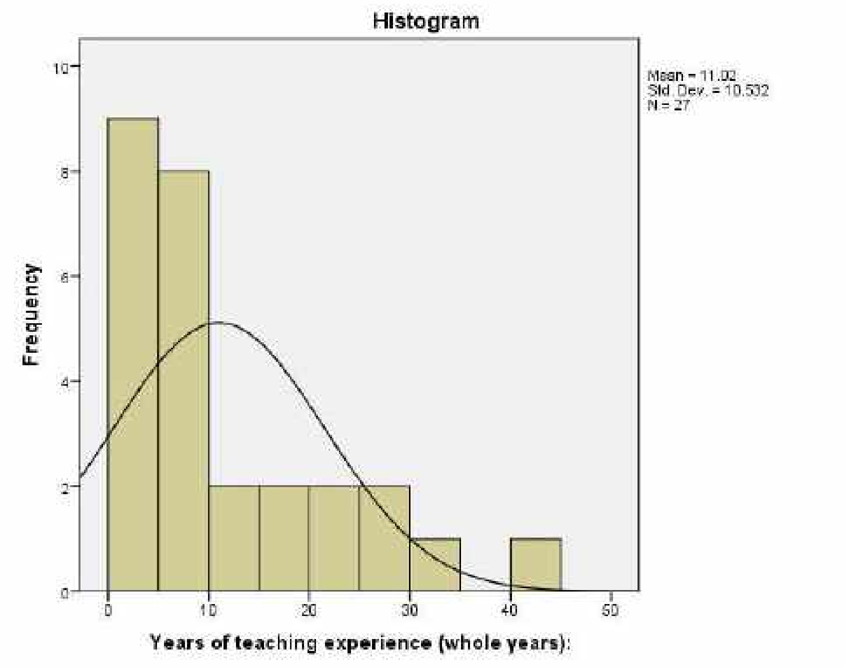



Figure 3.1 – Years Teaching (All Schools)

Participants were recruited from the three schools – Carlingford West Public School (CWPS), Oatlands Public School (OPS) and Parramatta East Public School (PEPS). Of these, most participants (n=15, 55.6%) were from CWPS, with smaller cohorts for OPS (n=3, 11.1%) and PEPS (n=9, 33.3%). A simple comparison of means was conducted to ascertain whether teaching experience varied between schools. As indicated in Table 3.3, experience did not vary greatly between CWPS and OPS, but these two groups had, on average, noticeably lower years of teaching experience when compared to PEPS teachers (M=21.22, SD=9.9), and PEPS teachers also showed elevated levels of variance within the group. The uneven sample sizes between the groups combined with a small overall sample size constrained the capacity to conduct further statistical analysis according to the participants' school.

Table 3.3 – Years Teaching by School

| ***School*** | **Mean** | **N** | **Std. Deviation** |
|---|---|---|---|
| *CWPS* | 4.97 | 15 | 4.530 |
| *OPS* | 10.67 | 3 | 12.662 |
| *PEPS* | 21.22 | 9 | 9.935 |
| *Total* | 11.02 | 27 | 10.532 |

The age range in terms of five-year increments (that is, the question asked in the questionnaire with ranges 20-24, 25-29, 30-34, 35-39, etc.) to some extent mirrored the *Years Teaching* variable, particularly with respect to teachers in the first ten years of their career. At the time of data gathering, most participants (n=15, 55.6%) were aged between 20 and 39 years, while a minority (n=11, 40.7%) were aged between 40 and 69 years. Taking the mid-point in each age category (for example 22 for the bracket 20-24), an approximate average age of 37.7 years was calculated.

Figure 3.2 shows the distribution of age ranges for 5- year increments.

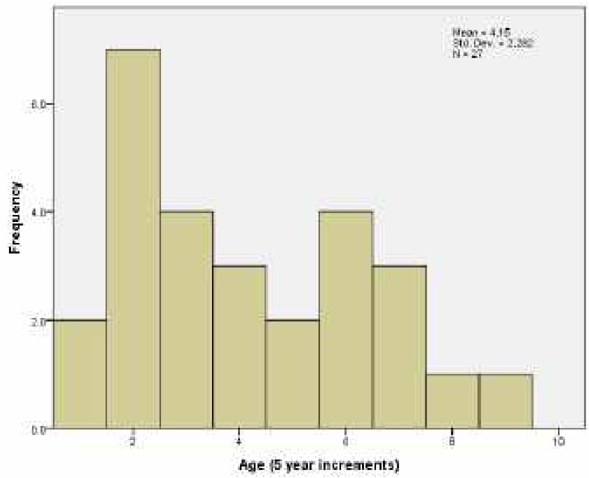



Figure 3.2 – Age (5-Year Increments, All Schools)

Of note, all participants (n=27, 100%) indicated that they had no prior experience teaching makerspaces lessons. Confidence with technology was measured with a five-point fully-anchored scale (0=Very Low, 1=Low, 2=Medium, 3=High, 4=Very High) in response to the question, “How would you rate your confidence in teaching with technology?”. In response to this question, a majority (n=16, 59.3%) indicated a score of 2 (“Medium”), with more participants indicating low confidence than high confidence.

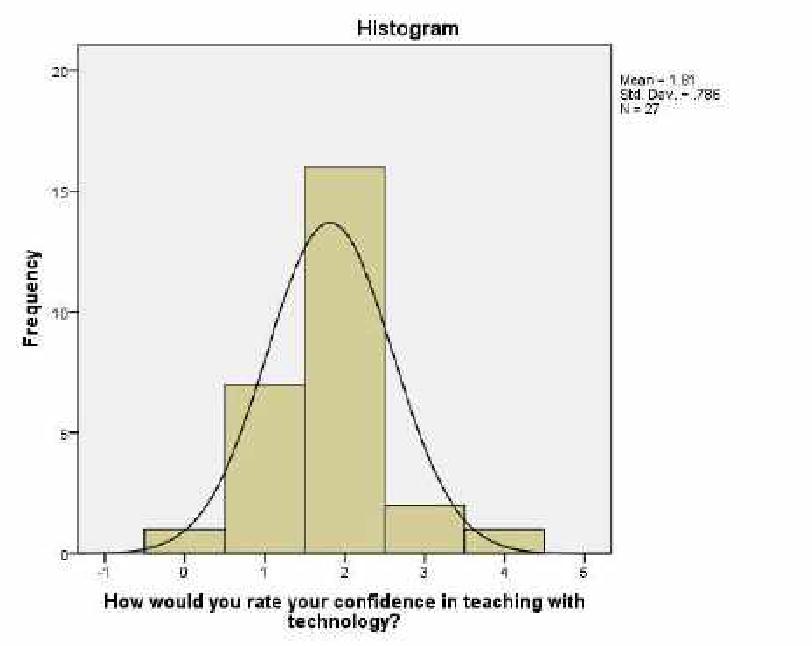



Figure 3.3 – Confidence with Technology (All Schools)

## 3.5 Ethics Approval

Ethical approval for this study was obtained from Macquarie University Human Research Ethics Committee (Ref: 5201700729R) and the NSW Department of Education State Education Research Approvals Process (SERAP Ref: 2017336). In accordance with ethical protocols, no individuals have been identified by name in this study and instead, pseudonyms have been used.

# PART II
# Professional Learning Analysis

# 4 Pre-Professional Learning Questionnaire

*The pre-professional learning questionnaire was conducted at the beginning of the project to ascertain the background knowledge and disposition of the 27 participating teachers. None of the participants had any prior experience teaching in makerspaces. For the seven-point Likert scales ranging from (0) "Strongly Disagree" to (6) "Strongly Agree", teachers reported, on average, high levels of enthusiasm to teach in makerspaces (M=5.2) but comparatively low levels of confidence (M=3.0). Teachers felt that it was important for students to acquire maker learning capabilities (M=5.0) but were less inclined to see themselves as makers (M=4.1). In their open-ended responses, many teachers saw makerspaces as space-enabling, innovative pedagogies, a tool for developing students' 21st century skills such as critical and creative thinking, and a vehicle for fostering positive learning behaviours such as risk-taking and engagement. The factors that the teachers felt would contribute to their success with makerspaces were ongoing collegial support, overcoming problems with technology infrastructure, having adequate resources, and being given time to explore and plan.*

## 4.1 Introduction to Pre-Professional Learning Questionnaire

This chapter reports on substantive findings from the pre-professional learning questionnaire delivered in the second week of August 2017. Before the first day of the professional learning commenced, participants completed an online questionnaire containing a mix of open and closed questions relating to their teaching experience and background, their confidence with technology, and their knowledge and dispositions towards makerspace-based learning. The full questionnaire is available in Appendix 1. Demographic results have already been reported in the previous chapter, whereas results relating to makerspaces learning and teaching are reported below.

## 4.2 Pre-Professional Learning Questionnaire – Likert Scale Items

Four items were measured using a fully-anchored seven-point scale ranging from (0) “Strongly Disagree” to (6) “Strongly Agree”, with (3) being “Neither Agree nor Disagree”. The items included the following four statements:

1. It is important for students to acquire maker learning capabilities;
2. I see myself as a ‘maker‘;
3. I feel confident to teach in makerspaces; and
4. I feel enthusiastic about teaching in makerspaces

Table 4.1 summarises the mean scores for each item for all 27 participants. Unsurprisingly, Items 2 and 3 relating to identity and confidence were lower-scored than Items 1 and 4 relating to values and enthusiasm. These two items also showed greater variance across the group.

Table 4.1 – Pre-Professional Learning Questionnaire Rating Items (All Schools)

| | **It is important for students to acquire maker learning capabilities** | **I see myself as a ‘maker‘** | **I feel confident to teach in makerspaces** | **I feel enthusiastic about teaching in makerspaces** |
|---|---|---|---|---|
| *Mean* | 5.00 | 4.07 | 3.04 | 5.22 |
| *Median* | 5.00 | 4.00 | 3.00 | 5.00 |
| *Std. Deviation* | .734 | 1.072 | 1.160 | .751 |

Examining the items in relation to the “How would you rate your confidence in teaching with technology?” question, a partial trend was observed between the responses to this question and responses for Items 2 and 3, as reflected in Table 4.2. Responses from those claiming *very low* and *low* levels of confidence in teaching with technology report, on average, lower scores for Item 3 (“I feel confident to teach in makerspaces”) than those in the medium group. Comparison with those claiming *high* and *very high* levels of confidence is fraught, given the very small number of teachers in these categories. However, it was interesting to note that the one teacher reporting *very high* confidence with technology somewhat disagreed with feeling confident to teach in makerspaces. Conversely – and perhaps encouragingly—Item 4 (“I feel enthusiastic about teaching in makerspaces”) appeared to bear no correlation with confidence. In other words, teachers at both ends of the self-reported scale strongly agreed that they felt enthusiastic about the idea of teaching with makerspaces. Given that no teachers reported any prior experience with makerspaces, the enthusiasm reported in response to this item had not been shaped in any way by prior experience.

Table 4.2 – Items Rated and Confidence with Technology (All Schools)

| ***How would you rate your confidence in teaching with technology?*** | | **It is important for students to acquire maker learning capabilities** | **I see myself as a 'maker'** | **I feel confident to teach in makerspaces** | **I feel enthusiastic about teaching in makerspaces** |
|---|---|---|---|---|---|
| *Very Low (n=1)* | Mean | 4.00 | 4.00 | 2.00 | 6.00 |
| | Std. Deviation | . | . | . | . |
| *Low (n=7)* | Mean | 5.29 | 3.71 | 2.71 | 5.00 |
| | Std. Deviation | .488 | 1.496 | 1.113 | .816 |
| *Medium (n=16)* | Mean | 5.06 | 4.19 | 3.19 | 5.25 |
| | N | 16 | 16 | 16 | 16 |
| | Std. Deviation | .680 | .911 | 1.167 | .775 |
| *High (n=2)* | Mean | 5.00 | 4.00 | 4.00 | 5.00 |
| | Std. Deviation | .000 | 1.414 | 1.414 | .000 |
| *Very High (n=1)* | Mean | 3.00 | 5.00 | 2.00 | 6.00 |
| | Std. Deviation | . | . | . | . |
| *Total (n=27)* | Mean | 5.00 | 4.07 | 3.04 | 5.22 |
| | Std. Deviation | .734 | 1.072 | 1.160 | .751 |

An examination of means across the three schools for all items showed only slight differences between schools, as shown in Table 4.3. Teachers from Oatlands Public School reported being, on average, the most enthusiastic about teaching in makerspaces, while also reported, on average, higher levels of confidence to teach in makerspaces. Teachers from Parramatta East Public School tended to perceive themselves more "as a maker", while teachers from Oatlands Public School tended to more greatly value the importance of students acquiring maker learning capabilities.

Table 4.3 – Items Rated by School

| | ***School:*** | **It is important for students to acquire maker learning capabilities** | **I see myself as a 'maker'** | **I feel confident to teach in makerspaces** | **I feel enthusiastic about teaching in makerspaces** |
|---|---|---|---|---|---|
| *CWPS (n=15)* | Mean | 5.00 | 3.93 | 3.00 | 5.20 |
| | Std. Deviation | .655 | 1.223 | 1.309 | .561 |
| *OPS (n=3)* | Mean | 5.33 | 4.00 | 3.33 | 5.67 |
| | Std. Deviation | .577 | 1.000 | 1.155 | .577 |
| *PEPS (n=9)* | Mean | 4.89 | 4.33 | 3.00 | 5.11 |
| | Std. Deviation | .928 | .866 | 1.000 | 1.054 |
| *Total* | Mean | 5.00 | 4.07 | 3.04 | 5.22 |
| | Std. Deviation | .734 | 1.072 | 1.160 | .751 |

Similarly, a comparison of age groups (10-year age increments was selected to increase group sizes) showed only slight differences between the increments for each of the items, suggesting that age was not a significant predictor of responses to the items. Table 4.4 shows these nuanced differences.

Table 4.4 – Items Rated by Age (10-Year Increments)

| ***Age (10-year increments)*** | | **It is important for students to acquire maker learning capabilities** | **I see myself as a 'maker'** | **I feel confident to teach in makerspaces** | **I feel enthusiastic about teaching in makerspaces** |
|---|---|---|---|---|---|
| *20-29 (n=9)* | Mean | 5.00 | 4.00 | 3.11 | 5.00 |
| | Std. Deviation | .500 | 1.000 | .928 | .500 |
| *30-39 (n=7)* | Mean | 5.00 | 4.14 | 2.86 | 5.29 |
| | Std. Deviation | .577 | 1.464 | 1.676 | .488 |
| *40-49 (n=6)* | Mean | 5.33 | 4.17 | 3.50 | 5.50 |
| | Std. Deviation | .816 | .983 | 1.049 | .837 |
| *50-59 (n=4)* | Mean | 4.50 | 4.25 | 2.50 | 5.75 |
| | Std. Deviation | 1.291 | .957 | 1.000 | .500 |
| *60-69 (n=1)* | Mean | 5.00 | 3.00 | 3.00 | 3.00 |
| | Std. Deviation | . | . | . | . |
| *Total* | Mean | 5.00 | 4.07 | 3.04 | 5.22 |
| | Std. Deviation | .734 | 1.072 | 1.160 | .751 |

## 4.3 Pre-Professional Learning Questionnaire – Qualitative Data Analysis

In addition to the rating scales and demographic questions that are discussed in the previous sections of this report, the pre-professional learning questionnaire posed six questions with open-ended (paragraph-style) text boxes. Three of the six questions were double-barrelled, denoted with "[and]" below. These questions served as follow-up questions to prompt participants for further ideas to address in their response:

1. To you, what are makerspaces?
2. What benefits do you envisage for your students from undertaking maker activities? [and] What do you anticipate they will learn?
3. What issues do you anticipate when teaching in makerspaces? [and] What do you think will constrain student learning in makerspaces?
4. What do you think will support learning in maker activities? [and] What pedagogical strategies can you suggest for teaching in makerspaces?
5. What support/s do you feel are the main things you need in order for your maker classes to be as successful as possible?
6. Please add any other thoughts or suggestions in the space below.

Table 4.5 shows the coding structure and hierarchy that emerged through the inductive analysis of the data. These data were analysed through segmenting, coding and the development of category systems in Nvivo. During the initial analysis, the team identified close connections between questions and the responses given. For example, Items 4 and 5 both address the theme of *support* within the school, with participants often articulating that elements supportive of learning (Item 4) would also support the success of maker classes (Item 5). Similarly, in articulating what they felt makerspaces were (Item 1), many participants referenced *benefits* that were further detailed in the envisaged benefits (Item 2). There was also often an inverse relationship between the specified issues (Item 3) and the supports that could address these issues (Items 4 and 5). Finally, the further thoughts prompt (Item 6) encouraged participants to add any thoughts they felt were appropriate, and these were often built on ideas explored in other responses.

Table 4.5 – Pre-Professional Learning Questionnaire Coding Structure Employed in QSR NVivo (Version 11)

| ***Code*** | **Number of Coding References** | **Number of Words Coded** |
|---:|---:|---:|
| *Makerspaces as...* | 33 | 352 |
| *Makerspaces as...\Pedagogy* | 12 | 157 |
| *Makerspaces as...\Opportunity-means* | 5 | 51 |
| *Makerspaces as...\Places-spaces* | 6 | 54 |
| *Makerspaces as...\Technology* | 7 | 42 |
| *Makerspaces as...\Curriculum* | 3 | 48 |
| *Enterprise Skills* | 37 | 416 |
| *Skills\Creativity* | 15 | 164 |
| *Skills\Critical Thinking* | 4 | 32 |
| *Skills\Inquiry* | 3 | 39 |
| *Skills\Problem Solving* | 15 | 181 |
| *Socio-behavioural (learning behaviours)* | 19 | 180 |
| *Socio-behavioural\Collaboration* | 10 | 88 |
| *Socio-behavioural \Engagement* | 3 | 21 |
| *Socio-behavioural \Enthusiasm* | 1 | 8 |
| *Socio-behavioural \Risk taking* | 5 | 63 |
| *Teacher Efficacy* | 29 | 290 |
| *Teacher Efficacy\Attitudes* | 2 | 13 |
| *Teacher Efficacy\Best pedagogies to employ* | 7 | 116 |
| *Teacher Efficacy\Confidence with technology* | 13 | 111 |
| *Teacher Efficacy\Support for learners* | 2 | 17 |
| *Teacher Efficacy\Unsure of what makerspaces are* | 5 | 33 |
| *External School Factors* | 60 | 521 |
| *External School Factors\Collegial Support* | 24 | 206 |
| *External School Factors \Problems with tech in the school* | 13 | 160 |
| *External School Factors\Resources* | 11 | 83 |
| *External School Factors\Time* | 12 | 72 |

Given the evident overlap of themes across these questions, the research team chose to apply theme codes across questions where this was warranted. Therefore, themes in this analysis – and in this report - were referenced not only to the specific item that most closely related, but to other items where the theme was also addressed. For example, benefits were all coded in relation to Item 2; but, where participants identified benefits in other items, these were also coded as benefits. These data helped to identify important relationships, including themes, patterns and semantic distinctions related to participants' perceptions of makerspaces. Throughout data analysis, recurrent themes, topics and issues were explored from the participants' perspectives with a view to establishing clear frames of reference.

As shown in Table 4.5, five first-order themes were developed, including: (1) *Makerspaces as*; (2) *Skills*; (3) *Socio-Behavioural (Learning Behaviours)*; (4) *Teacher Efficacy;* and (5) *External School Factors.* Column 2 (Number of Coding References) provides an indicator of the frequencies with which the themes occurred in the data, while Column 3 (Number of Words Coded) provides an indicator of the level of detail provided across the responses. The nature of these first order themes, as well as second order themes that emerged, are outlined in the next sub-section.

## 4.4 Theme 1: Makerspaces As…

The first of the first-order themes concerned teachers' beliefs about what makerspaces are and what they might enable. In data analysis, second-order themes emerged around the various ways of talking about makerspaces as a pedagogy, an opportunity or means to try a different form of learning, a purposive space for making, a form of technology, and a form of curriculum enactment. Interestingly, many responses specified only one of these areas.

Concrete descriptions appeared tied to makerspaces as *technology* and as *places and/or spaces*. Teachers that articulated makerspaces as a form of technology almost exclusively referenced 3D printing (n=6, 22.2%) as the main focus of what makerspaces were for them, such as Molly, who described makerspaces as "designing, making and printing 3D models" or Hannah, who said it was about "3D printing, which creates plastic and copper materials". The teachers focusing on makerspaces as *places and/or spaces* tended to take a broader view in their description of these, such as Amanda, for whom makerspaces were "a place for students to explore and create in an unstructured environment", Ella, who described makerspaces as "creative, open-ended design spaces [for] solving real life problems", or Amber, where they were simply "a place to share information and ideas".

For a larger group of teachers (n=10, 37%), makerspaces appeared to be an embodied form of pedagogy. These teachers directly and indirectly referenced a range of teaching and learning strategies, learning theories and other idealised forms of learning. Three specific models – Cooperative Learning, Project-Based Learning and Inquiry-Based Learning – were cited, and these stood alongside more generalised pedagogical approaches that emphasised student-led inquiry, open-ended tasks, group work, and authentic learning. Kirsten presented a relatively detailed response to Question 1 (*To you, what are makerspaces?*), describing makerspaces as "a program which encourages students to investigate, problem-solve and inquire based on a particular concept or question... Students then design and make a product which demonstrates their understanding of the concept". Julia noted the connection between the act of "making" and learner autonomy, describing a context where "students 'make' their own learning, investigating and researching, to formulate a plan and follow it through". Rachel saw makerspaces as an intersection between technology, skills and pedagogy, describing a space that "integrates technology, problem solving, investigations and Inquiry-Based Learning [IBL]". In a similar vein, several teachers described makerspaces as an opportunity for new and enhanced learning, such as Penny, Sophie, Mackenzie and Emma, all of whom saw them as an opportunity for their students to learn through creating.

Only five teachers (18.5%) indirectly referenced the curriculum and its relationship with makerspaces. Kirsten's conception of makerspaces as a "program" loosely suggested the embedding of activities within units of work that are tied to syllabus areas. Sally observed that she was "looking at using Science and Technology to solve problems", while Mackenzie tentatively described the possibility of the makerspace to serve as "a hook, maybe in [English] Literature or Science". In response to the second part of Question 3 (*What do you think will constrain student learning in makerspaces?*), Andrea referenced the curriculum as a constraining factor along with "resourcing, time… and 'tight reins'", all of which were seen to affect her ability to explore and implement makerspaces. Madalyn likewise argued that "a very full curriculum is always a hurdle".

## 4.5 Theme 2: Maker Skills

Despite the limited discussion of the relationship between curriculum and makerspaces, a large cohort of teachers (n=21, 77.8%) espoused the 21st century skills that could be developed through teaching and learning with makerspaces, with two of these skills – critical thinking and creative thinking – as featured among the ACARA's General Capabilities. Creativity (n=13, 48.1%) and problem solving (n=11, 40.7%) were the two most frequently-referenced skills, contrasted by comparatively fewer teachers referencing critical thinking (n=3, 11.1%) and inquiry (n=2, 7.4%). Among the creativity cohort, there were clear references to creativity as both a means and end in learning, and as an enabler of learners who, as Samantha put it, "gain confidence in their design and making abilities and hopefully become risk-takers in the way they approach learning". Teachers referencing problem solving tended to underscore the importance of "real-world" problems related to "big questions" and the need for students to, in Kim's words, "think outside the box". Julia stressed the need for the "ownership by students" of the questions, problems and their significance to the students' lives. Amanda believed that makerspaces could provide a vehicle for "showing students how to use technology to help with problem solving, and how to introduce it to a class – especially Kindergarten students". Madalyn suggested that problem solving was tied to "innovative thinking, design, collaborative skills and, of course, technological capabilities".

The smaller groups of teachers that cited critical thinking did not to elaborate on what this looked like in their experience. Emma simply offered critical thinking as a form of "evaluative thinking", while Diana grouped it with "open-ended tasks". For the teachers citing inquiry, task open-endedness, questions, research and student-led learning variously appeared to be attributes of inquiry in these teachers' ideal classrooms. Emma saw an important pedagogical approach in "student-led inquiries, which will be useful for these [makerspace] activities, giving them [the students] opportunities to direct their learning".

## 4.6 Theme 3: Learning Behaviours

Theme 3 concerned the learning behaviours that are often tied to the development of the 21st century skills in Theme 2. These learning behaviours were recognised by a large cohort of teachers (n=16, 59.3%) as both a means – that is, an enabler of effective learning with makerspaces – and ends – that is, an ideal behavioural outcome of learning with makerspaces. The most prominent learning behaviour identifiable in the data was effective collaboration, which for these teachers pertained to areas such as group work, cooperation, and peer assessment. Penny, Nadia and Alice all observed the importance of collaboration for effective group work in their classes, while Rachel saw the learning behaviour as tied to "engagement and meaningful learning". Sally believed that collaboration was an important learning behaviour for effective problem solving, while Corinne saw collaboration as equally applicable to teachers and students with "team teaching and peer mentoring".

Smaller cohorts of teachers identified engagement (n=3, 11.1%), enthusiasm (n=1, 3.7%), and risk-taking (n=5, 18.5%) as beneficial learning behaviours that might stem from learning in makerspaces. Engagement manifested for Julia as "staying on task", while Amanda saw it as essential for "persistence and resilience". Jasmine stressed the need for teachers to be open with their students "about taking risks", possibly implying a belief that teachers needed to take risks in their professional learning before encouraging students to take risks in their learning. In response to Question 2 (*What benefits do you envisage…?*), Amanda simply predicted, "I think they [the students] will be encouraged to take risks and learn from their mistakes along the way".

## 4.7 Theme 4: Teacher Efficacy

The theme of *teacher efficacy* relates to second-order themes about how teachers view themselves, their work, and their impact on the learning of their students. Perhaps at the heart of their internalised efficacy to teach in makerspaces, five teachers (18.5%) indicated that they did not, at the time of the survey, know what a makerspace was. This seems well-expressed by Jasmine, who in response to Question 3 (*What issues do you anticipate when teaching in makerspaces?*) acknowledged her "background knowledge or personal experiences to help them [the students] think of what they want to achieve and/or create". Other teachers in the group simply indicated "not sure" and "not 100% sure" in response to Question 1 (*To you, what are makerspaces?*). Related to their lack of experience with makerspaces, two teachers reported being unsure of how to best support their learners in a makerspace setting. Jane struggled with the idea of "guiding students and considering suggestions that will lead children to successful outcomes", while Tim drew attention to a desire for clear "scaffolds for younger students (Kindergarten)".

For almost half the teachers in the sample (n=13, 48.1%), confidence with technology appeared to be a factor that could shape the success of teaching and learning with makerspaces in their classrooms. As Julia elaborated, "I am fine as long as it [the technology] works, [but] not good at troubleshooting…". A self-identified "Low" (2) confident user of technology, Mackenzie implied that her "technological skills" represented a potential stumbling block for future teaching with makerspaces, along with her students' desires to "be finished first… and always be 'right'". Ella and Hannah acknowledged that they needed further training for their technology skills to be at the level where they could succeed with makerspaces, while Emma sought to develop her skills for using technology to "facilitate student-led inquiries".

Another internalised attribute of teacher efficacy for six participants (22.2%) was the question around what the best pedagogies were for teaching and learning in makerspaces. Sophie believed that her pedagogical strategies should include "open-ended activities, inquiry-based learning, questioning and discussion, collaborative learning and cooperative learning". Diana suggested that for her, "Bloom's Taxonomy would be a relevant pedagogical strategy to employ with the *Makers Empire 3D* app, utilising creating, evaluating, analysing and applying will be skills that students will need to demonstrate within [their use of] the app". Molly stated that she wanted to employ "explicit teaching and learning" to best support her students. The remaining teachers in this group appeared less sure of which pedagogies to employ. Kirsten asked, "As it [the software] is open-ended, how do I guide my students without turning the lessons into teacher-led?". This was a concern shared by Emma, who questioned "how to best use the technology to facilitate student-led inquiry". Hannah believed that "scaffolded learning" could play an important role in building the skills needed, suggesting that this would "encourage independent learning and creativity", but was unsure of what form the scaffolds might take.

Teacher attitudes were only specifically referenced by two teachers (7.4%). Corinne saw "traditional teaching attitudes" within her school community as potentially detrimental to the future success of makerspaces. Abigail recognised the need to change her own attitude, thereby "being open and allowing students to design and make spaces".

## 4.8 Theme 5: External School Factors

Closely tied to many of these internal self-perceptions were the perceived external factors relating the school environment that affect the teachers' work. Most prominently in this category, ten teachers (37.3%) believed that there were problems with the technology infrastructure within their school that they felt could impact on teaching and learning with makerspaces. Seven of these teachers specifically cited internet Wi-Fi connectivity as the main concern, while other teachers suspected that the software would not work effectively on older hardware. Diana predicted that "technology would not be readily available or not comply [work] when we need to use it for certain lessons", while Madalyn simply suspected that there would be "problems with the software".

Most teachers (n=17, 63%) identified the need for collegial support in order to teach effectively with makerspaces. Importantly, though, this theme existed across all the "Very Low" (1), "Low" (2) and "Medium" (3) categories – but excluded the "High" (4) and "Very High" (5) categories – from the earlier quantitative question (*How would you rate your confidence with technology?*). Thus, teachers reporting lower and medium levels of confidence with technology appeared more likely than their high and very high counterparts to identify a need for collegial support. As teachers in the low confidence group, Mackenzie, Molly, Hannah, and Jasmine all stressed the need for supportive colleagues and mentors. Mackenzie specifically asked for "a mentor, or collaboration with other participants", while Molly asked for "engaging support staff… and training". Hannah wanted to have "explicit planning" that would include the presence of "support staff in classrooms… when implementing makerspaces". Jasmine's support involved having mentors with whom "to discuss the learning that is happening in each classroom", perhaps so she could gain a better understanding of what would be possible and ensure that she was keeping pace with the progress of her colleagues. Teachers in the "medium" confidence group expressed a desire for support, though this appeared to be less about being "mentored" and more about opportunities to network, collaborate and appropriate resources. For example, both Madalyn and Ella wanted to observe Makers Empire experts teaching a "model" lesson but felt they could then develop their skills with team-teaching and collaboration. Rachel expressed a desire for "support staff" to be available, but qualified that this only needed to be "for initial setup". Diana wanted to network with other teachers outside of the sample for this study, "who are well-trained in the Makers Empire 3D app", while Sally simply desired "open discussion and resources".

Eight teachers (29.6%) specifically referenced "resources" in their response. For most of these teachers, it was unclear about what these resources included. For those that went into further detail, however, resources appeared to include adequate equipment, space, and lesson ideas. Sally was concerned about not having "enough iPads to use with the class", while Molly doubted whether "space… and appropriate equipment" would be available. Nadia stressed the need for "good Wi-Fi", while for Diana, there was a need for "plenty of readily available resources, [for developing] the skills and knowledge needed to deliver successful makerspaces lessons".

Finally, ten teachers (37%) referenced "time" as a broad concern for their successful teaching with makerspaces. As with "resources", most teachers did not provide further detail about why time was needed – whether for formal or informal professional learning, planning, administration, trouble-shooting and so on. The teachers that did provide further detail suggested, however, that time as it currently stood was insufficient for them to guarantee success. Sally simply wanted "time to get my head around it [the technology]", while Nadia alluded to the coordination of teaching, learning and assessment in "the busy school and class schedule". For Abigail, further time was needed "because it takes a long time to create these [3D objects]", adding that teachers needed to "allow students to have time to design and complete tasks in an open manner". Andrea, Madalyn and Molly all believed that the curriculum placed a time constraint on their teaching, suggesting that they would need to juggle makerspaces with other important curriculum areas.

## 4.9 Limitations of the Pre-Professional Learning Questionnaire

The aim of this chapter was to capture the data from the initial questionnaire delivered prior to the commencement of professional learning provided by Makers Empire to teachers in this sample. Two limitations are noted: first, the small sample of participants (n=27), which limited the quantitative analysis to descriptive statistics and comparisons of means; and, second, the level of detail teachers provided in response to open-ended questions. The sample analysed in the Pre-Professional Learning Questionnaire was small, making school-to-school comparisons fraught. Thus, a principally descriptive analysis of the data was conducted with some comparison of means between the groups identified (in this case schools and "ability groups" derived from the teachers' perceptions of confidence with technology). Responses to open ended questions typically ranged from one or two-word responses to short sentences usually no longer than two lines. This may have been related to participants' lack of familiarity with makerspaces or their internal motivation to provide extended responses. Nonetheless, the data and analysis did clearly suggest that participants in this study were very engaged and enthusiastic about future teaching and learning with makerspaces.

## 4.10 Pre-Professional Learning Questionnaire: Summary and Concluding Remarks

On a Likert Scale from "Strongly Disagree" (0) to "Strongly Agree" (6), the 27 teachers in general felt enthusiastic about teaching in makerspaces (M=5.22) and felt it was important for their students to acquire "maker" learning capabilities (M=5.00). However, they were less inclined to see themselves as a "maker" (M=4.07) and on average were not confident to teach in makerspaces (M=3.04). All participants reported no prior experience with makerspaces, making this an unaffected group of sorts and resulting in prior experience not being included as a factor or predictor of other variables. Most teachers in the group saw themselves as having "Medium" (3) confidence with technology, and this variable to some degree appeared to relate to the two items pertaining to perceptions of the teacher as "a maker" and their confidence about the idea of teaching in makerspaces. Regardless of confidence, a large majority of teachers were very enthusiastic about teaching with makerspaces – and, perhaps by extension, their involvement in the project.

Given that *none* of the teachers in this sample reported any prior experience teaching with makerspaces, the open-ended responses presented in this section were, in part, those of supposition, speculation and belief. These discourses reflected hopes and concerns – with no clear certainty – about what might happen in the future. The lack of prior experience therefore mediated other factors such as what teachers felt makerspaces were to them, the best pedagogies they could employ, and what skills and learning behaviours might stem from successful use in their classrooms. They saw makerspaces as places and spaces for designing and making, as an embodied form of pedagogy, and a way to enact curriculum. Teachers felt makerspaces would be of use to advance 21$^{st}$ century skills such as creativity, problem-solving, critical thinking and inquiry. They hoped their students would be able to develop their collaborative capabilities, risk taking, persistence and engagement through authentic tasks. To some degree, they appeared buoyed by their enthusiasm to try new technologies, and perhaps also buoyed by an overarching belief, or set of beliefs, about meaningful learning in the twenty-first century. These beliefs appeared embedded in the twenty-first century skills and learning behaviours they articulated, but it could equally be argued that many of their articulations were simply broad statements about teaching and learning that deserve, if not require, further elaboration and exemplification.

Teachers felt that their technological capabilities, the pedagogies that they used, and their attitudes would influence learning and teaching. They were concerned that their efforts would be affected by technological issues (such as the Wi-Fi network), the amount of support they received, the resources they could access, and the time required to successfully design and teach their modules. Thus, participants' in-depth knowledge of their school communities – including the colleagues, learners, infrastructure and support they have – appears clear and concrete. This local knowledge arguably represented a powerful reference point for these teachers moving forward, which could possibly lead them to seek the support, knowledge and resources they would need to successfully engage with the technology and support their learners.

# 5 The Professional Learning Program

*The professional learning program consisted of a full-day face-to-face workshop to introduce pedagogical foundations of design thinking and the use of the Makers Empire 3D app, followed by online professional learning support in the form of an Edmodo social networking page and four weekly live Zoom web-conferencing sessions, and a final full day face-to-face workshop to provide practical experience with the 3D printers and work on curriculum planning. The face-to-face professional learning was carefully sequenced, based on strong pedagogical foundations, suitably hands-on and collaborative, and presented by a facilitator who appeared to rapidly build rapport with teachers. The online sessions also provided less confident teachers with an opportunity to ask questions, receive additional instruction, and seek support. In the face-to-face sessions, some teachers initially struggled to operate the app. Teachers appeared to engage enthusiastically with, and appreciate, the professional learning program.*

## 5.1 Introduction to the Professional Learning Program

This chapter explains and analyses the professional learning program provided by Makers Empire. Researchers from the Macquarie team were present during the face-to-face training days that each teacher received. The first professional learning day for each teacher was held in the second week of August. Because of the large number of teachers in the cohort, the day was repeated with approximately half of the cohort attending each day (9th and 10th of August). The second professional learning day for each teacher was held in the second week of September (12th and 13th), with the two identical offerings once again being run to keep participant numbers manageable. In between the August and September professional learning days, teachers were invited to participate in an online Edmodo course page and weekly Adobe Connect web conferencing sessions, to help them familiarise themselves with the platform and think about how they might use it in their classes. The research team observed activity that transpired during these online professional learning sessions. In addition to describing each component of the program, this chapter refers to some anonymized comments from the participations that were captured during these observations. Note that while pseudonyms are used to reference teachers' comments elsewhere in this report, it was not possible to connect names with dialogue at this early stage of the study.

## 5.2 Day 1, Session 1 (Morning) – Introduction to Makerspaces

The opening session of the August professional learning day introduced participants to makerspaces, with a focus on maker pedagogies for 3D Design and Printing. Following general introductions from key personnel in the project team, the facilitator identified "learning by design" as a theme underpinning the session. Participants were first asked to design a tactile object using a piece of paper, and then to share the thinking that informed their design with a peer. Teachers then presented each other's designs along with insights about the making process.

This reflective activity helped to identify a number of themes pertaining to making. Many participants found themselves going with safe, established options such as "snowflakes" and "chatterboxes". Referring to her peer, one participant reported that "she designed the first thing that came into her head [a chatterbox]... because it was the easiest thing [to design]" while reporting in reference to herself that "I told myself I was going to design something safe". Some participants also found they were frustrated with being unable to produce a design that adequately reflected their ideas, such as when one participant noted that her peer "wanted the pattern of the snowflake [design] to be exact" but had failed to achieve this. Several participants found themselves adapting an initial idea – or changing course completely – because they didn't feel their idea was viable. As one participant related, "I wanted to make a crane, but after I made a mistake, I changed my mind". Although some participants admitted being unhappy with their final product, their peers were often quick to step in and defend the merit of the underlying design, as when one participant said of her peer that "she didn't think it [the design] was very creative, but I thought it was".

Following the paper making task, the facilitator presented the ideas of Jean Piaget and Seymour Papert. In education, Piaget is often best known as the exponent of the learning theory known as constructivism. Referencing a key quote from the theorist - "When you teach a child something you take away the chance for him to learn it for himself" - the facilitator drew attention the balance between explicit instruction and learner-led inquiry as an essential concern for maker pedagogies. Papert's Eight Ideas of Making were then presented as a summary of constructionism:

1. Learning by doing;
2. Building with technology;
3. Hard fun;
4. Learning to learn;
5. Taking time;
6. Failing well;
7. Teachers as learners; and
8. Learning together

The activity that followed this presentation involved groups of teachers being allocated one of the ideas to discuss both related examples stemming from their own experiences and questions they had about the idea. Each group was asked to record group discussion about the idea and document key findings on sticky notes that were posted underneath the idea heading around the room, as shown in Figure 5.1.


Figure 5.1 – Eight Big Ideas (Papert), Sticky Notes Activity

Several interesting themes were observed by the researchers during the discussion, including references to the importance of time, curriculum, trust, school culture, and willingness to make mistakes. Time appeared to relate closely to the curriculum, with both concepts influencing whether or not teachers felt they could support the intended approach to learning. As one participant explained, "If you give students enough time, they can learn well", while in references to the difficulties she faced, another participant remarked, "it's that time-curriculum problem again, isn't it?". Another participant explained that, for her, "the biggest question is time... How do you give them [the students] enough time to take control of their learning?", while a peer in her group responded, "we need to really look at de-cluttering the curriculum". One participant remarked, "teaching children to fail is where we need to be", admitting that she hadn't previously felt comfortable with failure, whether her own or that of her students. Asking and answering a pertinent question, one participant remarked, "how do you teach children to fail? Let's teach them that it's actually part of learning... that it's ok", further noting that until recently, she "had a school culture of not making mistakes". Summing up her group's discussion about failure, control, and the need for a changed mindset, one participant explained, "I think it's about having the [right] mindset with teachers... that we are allowing children to take control of their learning rather than trying to control it ourselves".

## 5.3 Day 1, Session 2 (Midday) – Practical Applications of Makerspaces and an Introduction to Design Thinking

In reference to a word cloud generated from a range of contemporary sources, common definitions "makerspace" were discussed. The facilitator then showed a series of videos where teachers and students discuss their work in makerspaces, and where various artefacts are modelled and shared.

In the activity that followed, teachers explored the IDEO *Design Thinking for Educators* model. Without explaining the concept, the facilitator asked teachers to discuss with a partner how they would define the concept. After some debriefing, the relationship between design thinking and problem solving was then discussed, with the facilitator explaining that design thinking is often applied to solve real problems, and involves a thorough assessment of the problem, brainstorming possible solutions, designing one or more of these solutions and improving the designs through further feedback and iterative development.

With reference to a video that showed Year 1 students solving a problem of "mixed up bags" (in a classroom where each student's school bags could not always be correctly identified), teachers were asked to describe, on sticky notes, the learning that took place in each of the five stages. The facilitator then introduced a slide that showed the five stages of the IDEO model, as in Figure 5.2, and asked teachers to place each of their sticky notes on one or more of the five stages of design, as shown in Figure 5.3.

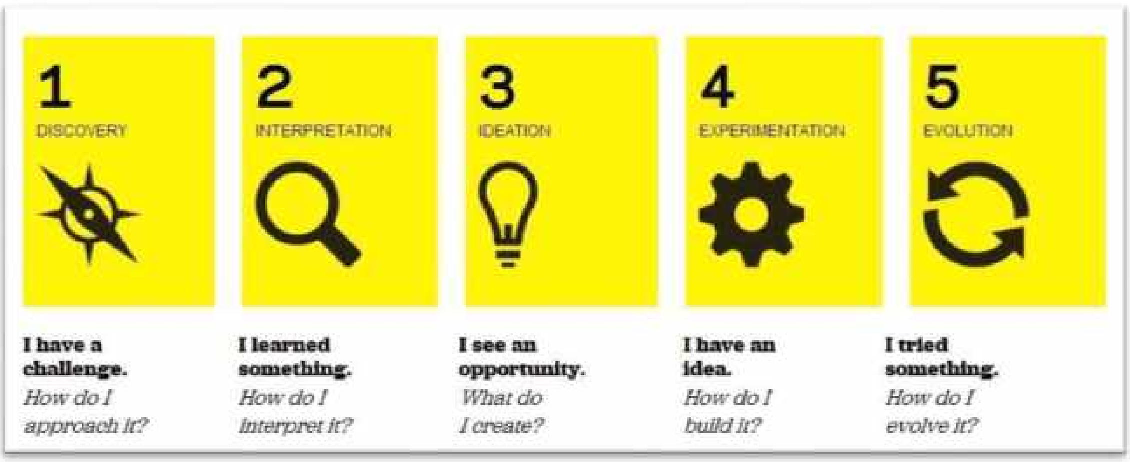



Figure 5.2 – The Five Phases of the Design Process (IDEO)

Figure 5.3 – Teachers Exploring the Five Stages of Design (IDEO)

In their evaluation of the activity, teachers agreed that while their ideas could be aligned with all five stages of the design process, it was often ambiguous as to which stage the idea best belonged. Further, teachers agreed that not all their ideas about evaluation, success, and reflection fit the model.

## 5.4 Day 1, Session 3 (Afternoon) – Pringles Design Task and Curriculum Mapping

The Pringles Design Task involved participants thinking about Pringles through the lens of each stage of the IDEO Design Thinking model:

1. Participants chose a story to serve as the basis for a problem (IDEO Stage 1, Discovery). During this stage, they identified problems such as: (a) what to do with the empty containers? (b) What to do about losing the lid? (c) how can we get to bottom of the container? and (d) what to do about broken chips?
2. Participants identified how that problem would be solved (IDEO Stage 2, Interpretation). The facilitator helped groups clearly distinguish between the problem, the solution conditions, and the attempt to find the solution.
3. Participants generated “50 Ideas in 5 minutes”, a strategy that involved rapidly recording down ideas without elaboration or justification (IDEO Stage 3, Ideation).
4. Each person in their group selected one idea that would be: (a) most likely to succeed; (b) so crazy it might be awesome; and (c) the “sweetheart” idea. Selecting one of these options, participants drew it on one post it note to iterate the idea further (IDEO Stage 4, Experimentation).
5. Participants gave a mock 30-second “elevator pitch” to the CEO of Pringles, circulating with other groups to do so. Pairs provided peer feedback, utilising strategies such as “Two Stars and a Wish” to scaffold the feedback.

Teachers were very engaged in the task, with many laughing as they shared ideas that one considered “crazy but cool”. The use of music and countdown visuals on the data projector by the facilitator added energy and a sense of immediacy to the task, and teachers generally found it easy to pursue, evaluate and discuss a wide range of ideas.

Following the Pringles activity, teachers spent time exploring technology components in new K-10 curricula. Teachers were first asked to consider how the IDEO model could align with contemporary curricula, with specific reference to the recently-released New South Wales *Science and Technology K-6 Syllabus*. The facilitator also asked teachers to relate their ideas to the Australian Curriculum "Critical and Creative Thinking" General Capability. Teachers received summaries of the *Science and Technology K-6 Syllabus* and Australian Curriculum General Capabilities and annotated those parts of the document that related to design thinking. Teachers in one group identified critical and creative forms of thinking as centrally related to design thinking. Another group felt design thinking could be applied to every K-6 curriculum area. The session then closed with the facilitator asking teachers to consider how they might plan immersive units of work that would embed the principles of design thinking explored in the session while meeting current and emerging curriculum demands.

## 5.5 Day 1, Session 4 (Afternoon) – Exploring 3D Printing and the *Makers Empire 3D* app

The facilitator asked teachers to informally rate their knowledge of 3D design and printing, with most teachers rating themselves as 2 out of 5 (fingers) for knowledge about 3D printing. Teachers then viewed several examples of how 3D printing can be used in the community, including for prosthetics, prefabricated houses, medical equipment, and clothing. The facilitator also presented and discussed a case study of a Year 6 student who had created a clip to hold cerebral palsy straps to a 2-year-old daughter of the teacher. Another case study similarly described a Year 6 student who had designed a disposal unit for his diabetes blood testing strips.

Teachers then discussed a range of reasons why 3D printing deserves focus in the curriculum. Reasons explored included:

- solving real world problems that matter to students;
- facilitating the design process cycle;
- promoting a growth mindset and the belief that it is ok to fail;
- fostering spatial awareness and thinking (moving from concrete to abstract forms of representation);
- allowing hands-on, concrete, kinaesthetic forms of learning;
- exploring inaccessible objects, and making abstract concepts into concrete objects; and
- promoting learning that is engaging and fun.

The final component to Day 1 was an introduction to the *Makers Empire 3D* app. Teachers were shown to the application platform, the login processes and available app features such as Shaper and Blocker that could be used to create and customise objects. Some aspects of the interface appeared difficult to learn and master.

The task required teachers to construct a nametag using available tools within the *Makers Empire 3D* app. Teachers were very engaged in the activity, and although some teachers mastered the tools more quickly than others, there was a collegial and supportive atmosphere, and struggling teachers were willing to ask for help (see Figure 5.4). Teachers appeared to be pleased when they successfully designed objects using the app, and several tech-savvy teachers particularly enjoyed troubleshooting problematic aspects of their colleagues' designs.

Figure 5.4 – Teachers Exploring the *Makers Empire 3D* app for the First Time

## 5.6 Online Professional Learning Support

The *Edmodo* page for the *Makerspaces in Primary School Settings* project was created by a Makers Empire Facilitator on August 8th, 2017, coinciding with the delivery of the first pair of professional learning days for staff in participating schools. The page had four main uses:

1. facilitating asynchronous communication between participants and Makers Empire – allowing for clarification, questions, and technical support;
2. posing of discussion questions by the facilitator to stimulate participants' thinking about makerspaces and related topics;
3. enabling the coordination of videoconferencing meetings; and
4. enabling the sharing of digital resources, including saved videoconferencing sessions, readings, lesson ideas, and related content.

Less than half of the sample of teachers (n=11, 40.7%) opted to participate in the Edmodo page, as measured by at least one recorded post within the page. It is possible that other teachers may have accessed the page and read content on one or more occasions, though log files were unavailable for Edmodo. For this reason, *participation* in the Edmodo space was defined in terms of there being one or more posts by the user within the page. Forty-four posts were recorded, which translates to an average four posts per participating user.

Teacher participation in Edmodo was explored in relation to five other variables that included: (1) the number of years teaching (YT); (2) the degree of confidence with technology; (3) the school; (4) the rating scale statement "I feel confident to teach with makerspaces"; and (5) the rating scale statement "I feel enthusiastic about teaching in makerspaces". Only two variables – years teaching and the rating scale item "I feel confident to teach in makerspaces" – showed clearly identifiable differences according to categorical groupings. Of these, the most marked differences were in relation to years teaching, with teachers participating in the Edmodo discussions being considerably more experienced than non-participating teachers (see Table 5.1).

Table 5.1 – Edmodo Participation by Years Teaching

| ***Did the teacher participate in Edmodo?*** | **Mean years of teaching** | **N** | **Std. Deviation** |
|---|---|---|---|
| *No* | 6.10 | 15 | 6.95 |
| *Yes* | 18.45 | 11 | 10.83 |
| *Total* | 11.33 | 26 | 10.62 |

The difference between participating and non-participating teachers was also evidenced – though much less marked – for the rating scale statement. Those who opted not to participate in Edmodo report, on average, being more confident to teach in makerspaces than those that participated (see Table 5.2).

Table 5.2 – Edmodo Participation by Confidence to Teach in Makerspaces

| ***Did the teacher participate in Edmodo?*** | **Mean confidence to teach in makerspaces** | **N** | **Std. Deviation** |
|---|---|---|---|
| *No* | 3.40 | 15 | 1.298 |
| *Yes* | 2.55 | 11 | .820 |
| *Total* | 3.04 | 26 | 1.183 |

Five topics were derived from examining and coding the content of posts, as shown in Table 5.3.

Table 5.3 – Edmodo Page Posts by Topic

| ***Posts By Topic:*** | **N=** | **% of Total Posts** |
|---|---|---|
| *Thanks and well wishes* | 8 | 18.18% |
| *Problem/technical support* | 11 | 25.00% |
| *Question about Makers Empire software* | 1 | 2.27% |
| *Response to discussion topic question* | 16 | 36.36% |
| *Confirmation of Zoom meeting involvement* | 8 | 18.18% |

Of note, most posts were related to either the discussion topics, or technical support. Technical support questions included those about how to log into the software within the school network, how to work out the Teacher Dashboard feature of the software, how to access the web conferencing software, and how to be added to the group email list.

On August 17th, August 24th, August 31st and September 8th, discussion topics were posted by the facilitator to stimulate further thinking on teaching and learning with makerspaces. The questions and their related topics were as follows:

1. What do students bring? [and] What are you favourite strategies for finding out what students bring?
2. How can we use technology to enhance how are students are currently making? [and] How can we use technology for making in ways that we couldn't without the technology?
3. Let's share our ideas for strategies that we can use with our students to facilitate the design thinking phases.
4. How can we make sure our design tasks are 'hard fun'? [and] What will you do to make sure your students are doing the thinking?

Question 1 prompted a discussion by four teachers on teaching strategies that they felt were suitable for exploring prior learning. In their response to the question, these teachers referenced the use of cognitive organisers, effective questioning, and active listening. Penny and Amanda agreed that brainstorms and mind maps are both effective ways of recording and organising students' ideas from prior learning, while Sally liked to ask her students "how they know an answer to a question is true" and support them in "being able to explain how they got an answer". Hannah grouped her students by both ability and prior experience, so that students with similar prior experiences were able to support each other in their learning.

For Question 2, the five responding teachers believed that technology was a powerful enabler of learning, and this appeared to intersect with other aspects of teaching and learning that included choice, differentiation, collaboration, creativity and modelling. Penny appreciated the number of available technology tools that allow students to make "end products" that evidence the deep thinking that occurred throughout the process of generating the product. Sally noted that technology allows for "alternate methods and avenues of learning" and believed that 21st century learning was "all about collaboration, planning and problem solving… as well as creativity and innovation… and communication is a big factor too". Amanda drew a comparison to "pen and paper learning", arguing that "students are able to be more creative with technology… because it helps them to create, draw and design things that may be beyond their abilities if only using a pencil and paper".

The three teachers responding to Question 3 highlighted the maker activities that they had already put in place in their classrooms. Penny had a "makers table" for an independent activity so that her students could develop offline making skills using common materials. In relation to this activity, she noted that the students "loved it", but questioned how she might "take it to the next level". Responding to this, the facilitator suggested that open-ended design tasks with criteria (such as the number of materials they could use, or a design that needs to move, roll or stand up) could add a further level of complexity to the task. In Sally's classroom, Kindergarten students similarly participated in "Discovery Time", which promoted a range of maker activities, with Sally finding that students could "be very creative with what we have given them". Amanda adopted "100 Ideas in 10 Minutes", an ideation strategy that the facilitator shared in the first professional learning day. She particularly liked to tell her students that "there are no silly ideas" – that all ideas were valid and could be explored and later tested for practicality. However, she conceded that this led to a number of impractical ideas and questioned how she could best help her students change their design concept to be more viable "without squashing their creativity".

None of the participating teachers responded to Question 4, which occurred at the end of Term 3. It was likely that teachers were extremely busy at this time. The second pair of professional learning days occurred in the following week, so it was equally likely that teachers may have felt there would be ample time to discuss their ideas further face-to-face in these sessions.

In addition to the Edmodo page, there were four Zoom web conferencing sessions as summarised in Table 5.4.

Table 5.4 – Summary of Web conferencing (Zoom) Sessions

| ***Session / Date*** | **No. Teachers** | **Content Focus** | **Commitment to Action** |
|---|---|---|---|
| *Session 1 (17th August)* | 7 | • Demonstrating: avatar customisation, saving to gallery, account/school/network settings, graphics settings<br>• Exploring/demonstrating: teacher dashboard, CSV file uploads, and sharing with students<br>• Introduction to discussion topics | • Setting up class via teachers' dashboard<br>• completing online training module in teachers' dashboard<br>• responding to discussion questions in Edmodo<br>• thinking about what to do for 3D design/printing project |
| *Session 2 (24th August)* | 18 | • Simple feedback on setting up dashboard with some questions/comments<br>• Discussion on integrating design thinking into makerspaces; integrating 3D design and printing<br>• Demonstration of work samples and explanation of how examples fit in with topics<br>• Explanation of the SAMR model and shows each of the domains in relation to 3D design and printing | (Same as Session 1) |
| *Session 3 (31st August )* | 15 | • Simple feedback on lesson ideas - hat hooks<br>• Discussion about "going deeper with DT"; exploring the IDEO model; speaking to each component, providing 1-2 strategies each component<br>• Discussion about Big Idea #3 - Hard Fun | • Choosing a lesson plan from the library and think about how 3D technology and DT have been integrated<br>• adding to the discussion about using technology to enhance making<br>• thinking about what you might do for your 3D designing/printing project |
| *Session 4 (7th September)* | 3 | • Further discussion on "Hard fun" and how to make design challenges engaging<br>• Discussion on open-endedness and having multiple entry points and pathways; "solving one problem in more than one way"<br>• Focus on questions for challenging assumptions, asking students to justify thinking, meta-questions asking students to think about their thinking | • Planning design thinking strategies to use with your students; and<br>• adding to our discussion topics |

The sessions held each week held on the same four days when the facilitator posted the discussion topics. Each session lasted approximately fifty-five minutes and included a PowerPoint presentation given by the facilitator, a focus on one of the "eight big ideas" from constructionist theory, and "commitment to action" in the form of homework for the following week.

As the data on the number of attendees suggests, these web conferencing sessions were largely seen as optional, with a relatively small number of teachers choosing to attend. Most of the facilitator content involved demonstrating aspects of the application platform, while there was a small portion of each session reserved for questions and discussion. The PowerPoint files that the facilitator used for the presentation component appeared very well-sequenced, with relevant and engaging information, examples, and key points. However, the same PowerPoint presentations naturally limited the time there was for discussions and questions.

## 5.7 Day 2, Session 1 (Morning) – "Unpacking" the 3D Printer and Evaluating the *Makers Empire 3D app*

The opening session of the second professional learning day held in September involved a detailed demonstration of the 3D printers recommended by the company Makers Empire (see Figure 5.5). The facilitator explained different types of filament that could be used, how to assemble and calibrate the printer, and how to print 3D objects from the *Makers Empire 3D* app using the application control panel. Researchers noted the use of technical language such as "filaments", "extruding", "ABS", "PLA" and similar terms.

Figure 5.5 – An Introduction to 3D Printing

Following the demonstration, teachers were asked to report back on their use of the *Makers Empire 3D* app in the intervening period between the professional learning days. Teachers' comments pointed to several main concerns they had with the application. First, several teachers agreed there was a need to have the option to turn off 'token' mode in the application platform to encourage students to complete their designs in a timely fashion. These teachers believed that students would focus heavily on generating more tokens through buying and selling objects rather than focusing on their designs, and the system made the app "gamified" where the focus could have been more on creativity. Second, several Kindergarten teachers requested what they described as a "small kids' mode", containing a basic set of tools, with larger icons and controls, simplified manipulation of designs, formative feedback and correctives – all suitable to a very young user base. Third, teachers argued there needed to be "sandbox" time structured into the units of work, where children could explore and investigate the properties of tools. Fourth, some teachers commented on their use of Blocker, expressing a desire to be able to add words to the designs when working with this feature. Finally, teachers reported that creating objects with the Shaper tool required them to think about how the design could be made up of more than one shape.

In relation to 3D printing, several teachers expressed concerns about what they observed during the demonstration. In particular, teachers recognised the slow speed at which objects could be printed, noting the impact this could have on a whole class when students wanted to print their designs, or when a 3D printer was shared across two or more classes.

Following the discussion of the 3D printing process and application platform, teachers raised five suggestions for how design thinking skills might be best developed in their context:

1. making help posters to which teachers and students can refer when troubleshooting issues that emerge in the design process;
2. giving students ample exploratory time, wherein they explore the capability and actions of the tools before applying them to specific design projects;
3. ensuring that the design process is relevant to the interests and capabilities of the students, with learning that is embedded in the process of problem solving complex and real-world problems;
4. accepting that trial and error are important to learning, but require reflection so that students can learn from their mistakes; and
5. providing opportunities to decorate products, given that the 3D printers are only able to print in one colour.

## 5.8 Day 2, Session 2 (Midday/Afternoon) – Planning and Testing Design Ideas

Spread over both midday and afternoon school periods, the final session afforded teachers the opportunity to begin collaboratively planning their makerspaces units of work. To integrate the technology into these units, the facilitator suggested five key questions, shown in Figure 5.6.

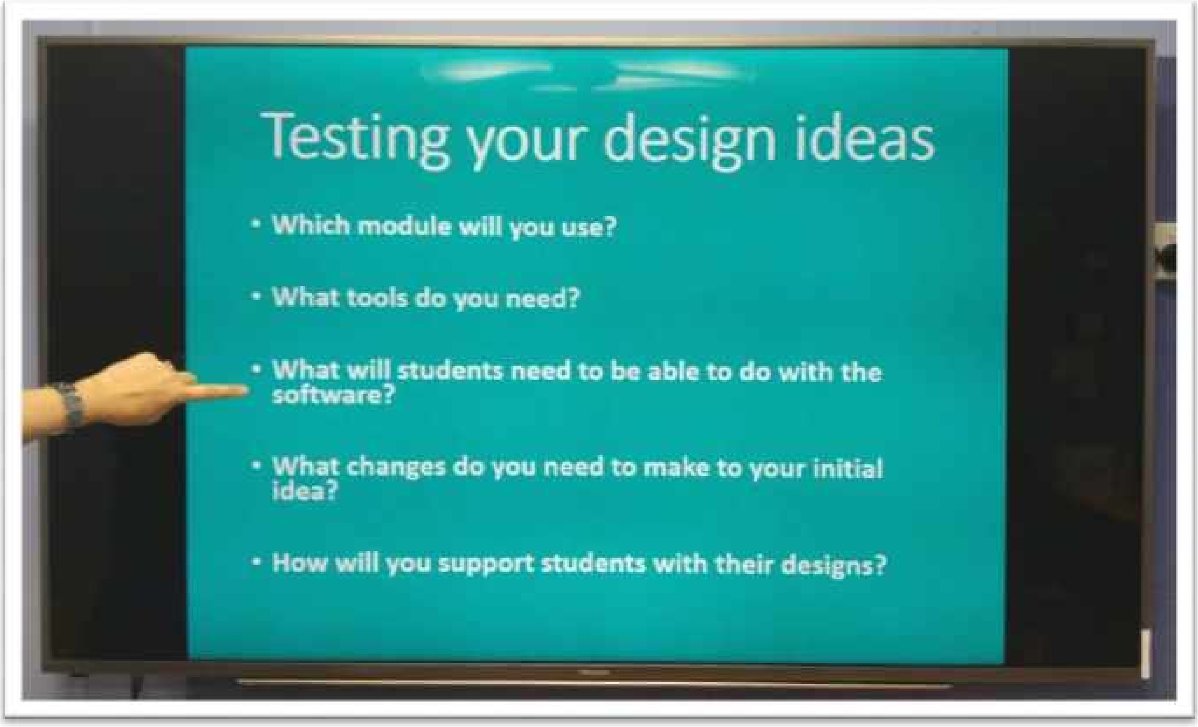



Figure 5.6 – Testing Your Design Ideas - Five Key Questions

Teachers then worked within their teams to brainstorm possible topics that could form the basis of their units of work. The following topics were discussed:

- extending existing units being taught to include 3D modelling;
- having students designing their own Australian animals;
- designing reusable planters, solving the problem of existing planter containers that crack and do not drain properly;
- creating an emblem for a 'bump it up' wall;
- creating Christmas presents for themselves or for others;
- constructing human-made environments that can serve as model animal habitats;
- using nature's pedagogy as 'Inspired artwork';
- creating human-made artefacts from the environment; and
- constructing Christmas decorations for a class tree.

The final component of the session involved the facilitator providing advice to assist the teachers when developing the brainstormed topics into full units of work. The facilitator asked teachers to consider how the unit would be introduced to their students, how the stages of the IDEO Design Thinking model could be mapped to the key stages in the unit, and which resources could be used to support learning. The facilitator shared scaffolded design ideas to demonstrate possible approaches. Teachers agreed that this final component was a very worthwhile, since they had the time to share pragmatic strategies on how they would manage the design process in the classroom. When the second day concluded, teachers appeared enthusiastic about the next stages of planning and implementing their makerspaces.

## 5.9 Limitations of the Professional Learning Program Observations

The aims of this chapter were: first, to describe the blended professional learning program offered by Makers Empire in August and September 2017; and, second, to explain key observations from the research team about the program and participants' engagement in the program. Researchers' observations were separately recorded and collated to inform both aims, though the notes that researchers recorded were unstructured and did not follow a protocol (unlike, for example, the protocol used to conduct lesson observations later in the project). Although the activities are described factually with the intention of accurately conveying the professional learning that was delivered, the commentary on these activities often fundamentally represents the opinions of individuals in the research team. While effort was made to capture participants' comments and opinions, doing so was often ad-hoc, dependent on where the researchers were situated in the room and on which of the many conversations that took place throughout the program were heard. Finally, it was generally not practical to identify participants by name when quickly recording comments and opinions, meaning that all commentary from teachers in this chapter was, in contrast to the rest of the report, anonymous.

Despite limitations noted, the chapter provides a detailed account of the professional learning that took place and should serve as a record of why the program was, on the whole, so well-received by teachers. The chapter also helps to contextualise the findings in the chapters that follow. In particular, Chapter 6 provides a detailed analysis of participants' perceptions of the program, helping to further contextualise the observations presented in this chapter.

## 5.10 Professional Learning Program Observations: Summary and Concluding Remarks

The observations reported in this chapter speak to a professional learning program that was carefully designed, informed by evidence, and expertly-facilitated. The program encouraged teachers to adopt the role of makers and apply the maker mindset to offline and online making activities, and to the learning design activities where participants commenced developing their makerspaces units of work. Requiring no prior knowledge or experience teaching in makerspaces, the program appeared equally accessible and relevant to teachers at all career stages and with varying levels of technology expertise. The analysis of both the Edmodo page activity and Zoom sessions suggests, however, that these forms of online support may have played a role in supporting less tech-savvy teachers, many of whom were very experienced in their years teaching (M=18.45). Lesser-experienced teachers – particularly those in the first ten years of service – were far less likely to participate in the page, perhaps because they felt that they had the requisite knowledge and skills to use the Makers Empire software.

In both face-to-face and online spaces, the participating teachers did not appear afraid to ask questions, seek support or share ideas. The interactions with the facilitator suggested that there was mutual rapport, and that participants appreciated the support they received via the professional learning program. In the face-to-face mode, the facilitator quickly built rapport with all participants. Online, the participation for the *Edmodo* discussion forum sessions was small when viewed in relation to the overall sample. It should be noted, nonetheless, that the *Edmodo* page provided an important point of communication between the facilitator and participants, but also between participants from different schools that otherwise were not able to easily meet and discuss ideas outside of the face-to-face sessions.

# 6 Post-Professional Learning Questionnaire

*The post-professional learning questionnaire was conducted directly after the professional learning program to gauge participants' development and explore their perceptions of the professional learning. Responses to the seven-point Likert scale questions ranging from (0) "Strongly Disagree" to (6) "Strongly Agree" confirmed that on average, teachers viewed the professional learning program as well-designed ($M=4.6$). Teachers' confidence to teach in makerspaces rose to $M=4.6$, from an initial level of $M=3.0$, which was a statistically significant increase, $t(26)=-4.875$, $p=0.001$. Enthusiasm to teach in makerspaces reduced slightly to a $M=4.8$, though this decrease was not shown to be statistically significant. Teachers expressed a strong preference for face-to-face professional learning with ample provision for hands-on learning, expert guidance and time for curriculum planning. Teachers' main concerns going forward were mastering the technology, having enough time for curriculum planning and implementation, teaching necessary knowledge and skills (including technological skills), and overcoming anticipated technology infrastructure issues.*

## 6.1 Introduction to the Post-Professional Learning Questionnaire

This chapter reports on the analysis of the post-professional learning questionnaire, delivered following the conclusion of the professional learning program in the second week of September 2017. All teachers who participated in the pre-professional learning questionnaire also completed the post-professional learning questionnaire (n=27). The chapter includes both discrete analysis of the post-questionnaire data as well as a combined analysis of variables across both pre- and post- stages. The full post-professional learning questionnaire instrument is available in Appendix 2.

## 6.2 Post-Professional Learning Questionnaire – Likert Scale Items

Three items were measured using a fully-anchored seven-point scale ranging from (0) "Strongly Disagree" to (6) "Strongly Agree", with (3) being "Neither Agree nor Disagree". The items included the following three statements:

1. This professional learning program was well designed;
2. Following this professional learning program, I feel confident to teach in makerspaces; and
3. Following this professional learning program, I feel enthusiastic about teaching in makerspaces.

It is important to note that the constructs of "confidence" and "enthusiasm" were both addressed in the pre-professional learning questionnaire; thus, they provided useful points of comparison to the earlier dataset. However, all three items shown above clearly focus on the professional learning program that was delivered by the Makers Empire facilitator. This should be noted when making comparisons to the earlier, more generalised statements "I feel confident to teach in makerspaces" (confidence) and "I feel enthusiastic about teaching in makerspaces" (enthusiasm).

Table 6.1 summarises the mean scores of each item for all 27 participants. Of note, mean scores for all three items were high, with Item 3 (enthusiasm) being the highest-rated item:

Table 6.1 – Post-Professional Learning Questionnaire Items Rated (All Schools)

| | **This professional learning program was well designed** | **Following this professional learning program, I feel confident to teach in makerspaces** | **Following this professional learning program, I feel enthusiastic about teaching in makerspaces** |
|---|---|---|---|
| *Mean* | 4.63 | 4.44 | 4.78 |
| *Median* | 5.00 | 5.00 | 5.00 |
| *Std. Deviation* | 1.245 | .801 | 1.155 |

A comparison of means of these items by *School* and in relation to both *Years Teaching* and *Edmodo Participation* was conducted but did not show any marked differences. However, a comparison of means by age (for ease of reference, 10-year increments) showed observable difference between the "40-49" category and other categories. It appeared that teachers in this category reported, on average, higher ratings of the three items, as shown in Table 6.2.

Table 6.2 – Items Rated by Age (10-Year Increments)

| | ***Age (10-year increments)*** | **This professional learning program was well designed** | **Following this professional learning program I feel confident to teach in makerspaces** | **Following this professional learning program I feel enthusiastic about teaching in makerspaces** |
|---|---|---|---|---|
| *20-29* | Mean | 4.44 | 4.11 | 4.78 |
| *(n=9)* | Std. Deviation | 1.014 | .601 | .441 |
| *30-39* | Mean | 4.14 | 4.57 | 4.29 |
| *(n=7)* | Std. Deviation | 1.864 | .535 | 1.890 |
| *40-49* | Mean | 5.33 | 4.83 | 5.50 |
| *(n=6)* | Std. Deviation | .516 | .408 | .548 |
| *50-59* | Mean | 4.75 | 4.25 | 4.50 |
| *(n=4)* | Std. Deviation | 1.258 | 1.708 | 1.291 |
| *60-69* | Mean | 5.00 | 5.00 | 5.00 |
| *(n=1)* | Std. Deviation | . | . | . |
| *Total* | Mean | 4.63 | 4.44 | 4.78 |
| *(n=27)* | Std. Deviation | 1.245 | .801 | 1.155 |

Given the use of the common 7-point scale, confidence and enthusiasm teaching in makerspaces for the whole group pre-professional learning was compared to post-professional learning results. This comparison is shown in Table 6.3. Of note, there is a marked difference in average reported confidence prior to the professional learning (M = 3.04), compared to following the professional learning (M = 4.44). A paired T-test found that this difference in confidence, was significant $t(26) = -4.875$, $p=0.000$. There was also a slight decrease in the mean level of enthusiasm, though this was not shown to be significant, $t(26)=1.8$, $p=0.09$. If there was a decrease in enthusiasm not otherwise attributable to chance, it is possible that it was attributable to the timing of the workshop (last week of term), or to the impending work that teachers would have to undertake to prepare their modules.

Table 6.3 – Paired Sample T-Test: Confidence and Enthusiasm

| | **Pre-Professional Learning Questionnaire** | | **Post-Professional Learning Questionnaire** | | **t** | **df** | **Sig (2-tailed)** |
|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | | | |
| *I feel confident to teach in makerspaces* | 3.04 | 1.16 | 5.0 | .62 | -4.875 | 26 | .000 |
| *I feel enthusiastic about teaching in makerspaces* | 5.22 | .75 | 5.56 | .58 | 1.762 | 26 | .090 |

Finally, the *Confidence with Technology* variable from the pre-professional learning questionnaire – which relates to the participants' generalised views of their confidence with technology – was used as a grouping variable for the items rated in both pre- and post- questionnaires. Three clusters were created by grouping scores of 1 and 2 ("Very Low" and "Low"), and scores of 4 and 5 ("High and "Very High"), while keeping the "Medium" category separate. This analysis is shown in Table 6.4.

Of note, for the "Low and Very Low" cluster, there was a very large mean increase in confidence with teaching in makerspaces (from M = 2.63 to M = 4.38), placing this group at similar levels of confidence as the "Medium" and "High and Very High" clusters at the post-professional learning stage. A similar, though less-marked increase in confidence could be observed for the "Medium" group (from M = 3.19 to M = 4.50), while the "High and Very High" category expectedly showed the least-marked increase (from M = 3.33 to M = 4.33). These gains are shown in Table 6.4 and Figure 6.1.

Table 6.4 – Confidence and Enthusiasm Teaching in Makerspaces by Confidence with Technology Clusters

| *Confidence with technology - three groups* | | I feel confident to teach in | I feel enthusiastic about teaching in | Following this professional | Following this professional |
|---|---|---|---|---|---|
| *Low or Very Low (n=8)* | Mean | 2.63 | 5.13 | 4.38 | 4.63 |
| | Std. Deviation | 1.061 | .835 | 1.188 | .744 |
| *Medium (n=16)* | Mean | 3.19 | 5.25 | 4.50 | 4.75 |
| | Std. Deviation | 1.167 | .775 | .516 | 1.390 |
| *High or Very High (n=3)* | Mean | 3.33 | 5.33 | 4.33 | 5.33 |
| | Std. Deviation | 1.528 | .577 | 1.155 | .577 |
| *Total (n=27)* | Mean | 3.04 | 5.22 | 4.44 | 4.78 |
| | Std. Deviation | 1.160 | .751 | .801 | 1.155 |

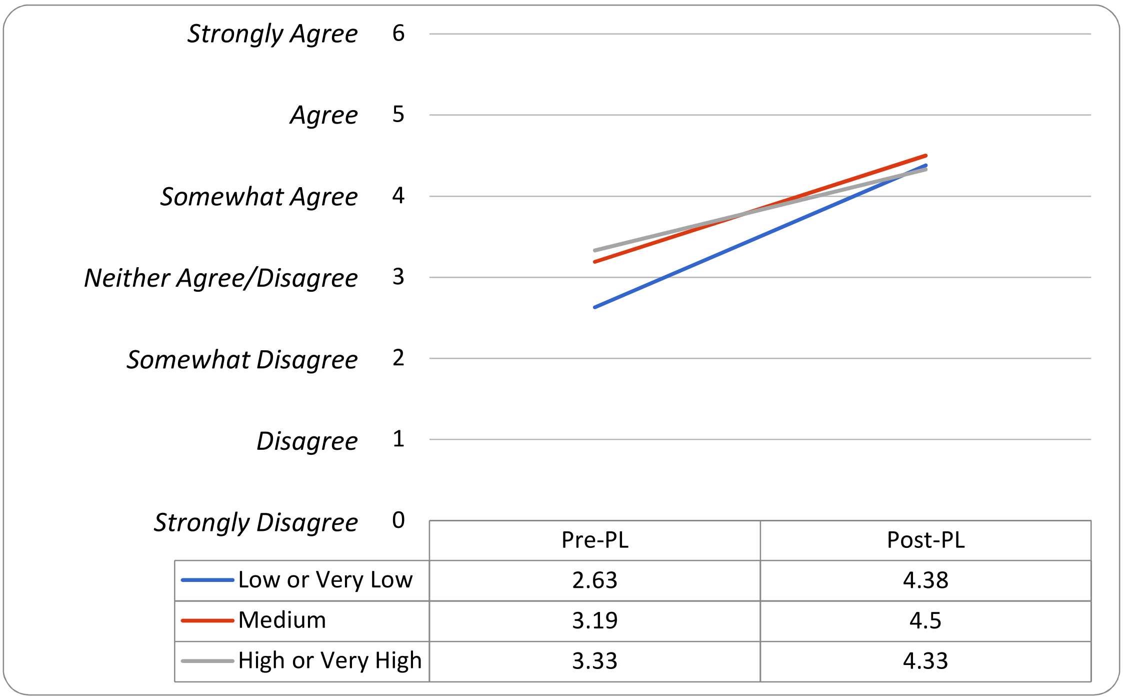



Figure 6.1 – Pre-PL Confidence to Teach in Makerspaces by Technology Confidence Groups

## 6.3 Post-Professional Learning Questionnaire Qualitative Analysis

The post-professional learning questionnaire included seven open questions. Of these, Questions 1-3 focused on the professional learning program, while Questions 4-7 invited respondents to explore related issues that included the value of makerspaces professional learning programs in general, the concerns held and supports needed relating to implementation, and any further thoughts:

1. What were the main things you learnt as a result of this professional learning program?
2. What were the best parts of this professional learning program?
3. What suggestions do you have about how to improve this professional learning program?
4. Do you think that it is important to have professional learning for teaching in makerspaces? If so, why? If not, why not?
5. What concerns do you now have about teaching in makerspaces?
6. What support do you feel you need from here for your maker classes to be as successful as possible?
7. Please add any other thoughts or suggestions in the space below.

Importantly, the level of detail provided by some participants increased considerably from pre- to post-responses, and this is reflected by examining both the number of coding references and number of words coded. The presence of fewer coding references coupled with more words coded indicates that participants could focus on individual issues and elaborate in greater detail on these issues. This finding stood in contrast to the level of detail provided in the pre-professional learning questionnaire, where participants often listed several issues but provided little or no elaboration on these issues. The finding was particularly evident in relation to the first-order themes of *Teacher Efficacy* and *External School Factors*, perhaps due to the nature of the questions that focused clearly on the teachers' engagement with the professional learning program, as well as on their thoughts about concerns and supports needed.

Table 6.5 shows the category system that emerged from the inductive analysis of responses to the seven open questions. Three first order themes emerged, including: (1) *Key Outcomes*; (2) *Suggested Improvements*; and (3) *Concerns Moving Forward.* Column 2 (Number of Coding References) provides an indicator of the frequencies with which the themes occurred in the data, while Column 3 (Number of Words Coded) provides an indicator of the level of detail provided across the responses. Each of these first order themes and their corresponding second order themes are unpacked below.

## 6.4 'Theme 1: *Key Outcomes* from the Professional Learning Program

Almost all the teachers surveyed (n=25, 92.6%) commented on what they felt were positive outcomes from their involvement in the program. Most significantly, a sizeable portion of teachers (n=16, 59.3%) referenced their own confidence with technology. Whereas this often appeared through a deficit lens in the pre-questionnaire data, many the responses here suggested a more positive outlook in relation to the teacher's confidence. Many teachers in this group simply referenced now knowing how to use the *Makers Empire 3D* app and 3D print objects. A particularly reluctant user of technology, Mackenzie was happy that she could "use 3D technology to further enhance children's thinking… that it doesn't need to replace what we already do but will add another level to their thinking". Dawn described some concrete achievements when she stated, "I learned how to set up my class with the QR code, how to use the app to login and create designs, new skills for changing designs, and different modules [app features] for students to use".

Table 6.5 – Coding Structure Employed in NVivo - Pre- and Post- Questionnaires

| ***Code*** | **Number of Coding References** | **Number of Words Coded** |
|---:|---:|---:|
| *Key Outcomes* | 74 | 1,605 |
| *Key Outcomes\Confidence with technology* | 26 | 500 |
| *Key Outcomes\Knowledge of Makerspaces* | 13 | 290 |
| *Key Outcomes\Maker Pedagogies* | 7 | 182 |
| *Key Outcomes\Opportunities to plan* | 6 | 137 |
| *Key Outcomes\Teachers' Enterprise Skills* | 12 | 293 |
| *Key Outcomes\Teachers' Technical Skills* | 10 | 203 |
| *Suggested Improvements* | 52 | 1,076 |
| *Suggested Improvements\Content* | 6 | 102 |
| *Suggested Improvements\Face-to-Face vs Online* | 36 | 705 |
| *Suggested Improvements\Structure* | 4 | 128 |
| *Suggested Improvements\Training Support* | 6 | 141 |
| *Concerns Moving Forward* | 109 | 2,136 |
| *Concerns Moving Forward\Collegial Support* | 45 | 745 |
| *Concerns Moving Forward\Problems with technology in school* | 13 | 182 |
| *Concerns Moving Forward\Resources* | 17 | 365 |
| *Concerns Moving Forward\Support for learners* | 12 | 260 |
| *Concerns Moving Forward\Time* | 22 | 584 |

For a similar portion of teachers in the sample (n=11, 40.7%), knowledge of what makerspaces are represented a key positive outcome of their involvement in the professional learning program. Jasmine got to the heart of the problem in her response to why professional learning in this area is important when she stated, "many teachers and students are unfamiliar with the concept of makerspaces… [professional learning] provides more confidence and guidelines for teachers to introduce it to their children". Madalyn was pleased that she knew "what makerspaces are", along with having "a better understanding of what Makers Empire is all about and the benefits of this type of makerspace learning for children". Emma identified the primary benefit of the program for her in noting, "I learned about what makerspaces are and how to use Makers Empire". Corrine summed up her gains in knowledge as having "a better understanding of what Makers Empire is all about and the benefits of this type of makerspace learning for children".

Seven teachers (25.9%) commented on how their understanding of maker pedagogies improved following the program. Andrea saw her growing understanding of design thinking as useful for supporting "the launch cycle" and design process. In recognising the value of design thinking, Penny admitted that she had "not looked carefully at it [design thinking] before, other than in the context of Project-Based Learning". Madalyn believed that learning about maker pedagogies deepened her understanding of constructivism, finding the professional learning "beneficial and very relevant in terms of how pedagogy needs to develop to meet the needs of today's learners". After the program, Tim held the view that maker pedagogies aligned strongly with STEM pedagogies, while Hannah saw connections between contemporary pedagogies and 3D printing. Diana felt that she was more able to support open-ended inquiry and "giving students a problem to solve, so that they are more engaged in the task". While it was not explicitly named as an instructional model during the program, Nadia felt that the learning theories she explored were "in line with the way Project-Based Learning would occur" in her classroom.

A similar number of teachers (n=5, 18.5%) referenced opportunities to collaboratively plan and develop maker units of work as a positive outcome from the program. Teachers were glad that the program afforded some time for them to work in teams to begin designing their units and, for several teachers, this time appeared to have been the most valuable component of their professional learning. As Abigail elaborated, "there was a lot more planning time for the [learning] Stage, which allowed us to really develop our ideas… and as a result, gave us more of a direction about what will be created and how it can be achieved". Emma described the primary benefit of the program as "being able to collaborate with colleagues on how to use this technology in specific units of work" while adding that "learning about the technology and being given time to experiment was also valuable". Diana was grateful that she "was given time to plan and program for our upcoming units". Jenna suggested that "having each Stage working on the same day" would foster greater collaboration both within teams and between schools.

There were 11 teachers (40.7%) who specifically commented on gains in their $21^{st}$ century skills through the program. Significantly, Rachel, Ella, Sally, Jasmine, Emma and Molly all agreed that their understanding of problem-solving and how to develop problem-solving skills improved. Sally described this as "looking at problem solving in a new way", whereas Jasmine felt she would be better at "approaching real life problems rather than teaching the concept as it is". Emma felt she "learned about how to encourage students to design to solve a problem". For other teachers in the group, skills relating to the design process were also key. Andrea felt she now had a better grounding of "the process of design thinking, and ideas to support each step", while Jenna now understood "the design thinking process that occurs when creating a 3D item". Eight teachers (29.6%) commented on how their technical skills had improved. Ella's articulation of these skills as "operating a 3D printer and using the *Makers Empire* software" appeared consistent with other teachers' views of the skills gained.

## 6.5 Theme 2: Best Aspects and Suggested Improvements for the Program

Among the second-order themes referenced, teachers' views on what constitutes the best forms of professional learning were addressed by over two thirds of the sample (n=21, 77.8%). Responses coded with this theme included a wide range of succinct statements about important attributes of makerspaces professional learning, as well as several more in-depth responses. There were references by nine teachers (33.3%) to "hands on" and "experiential" learning. Teachers in this group seemed to appreciate the opportunity to learn about makerspaces by through actual experience with the relevant hardware and software. Rachel believed that more hands-on time in future professional learning "would help other staff to gain confidence when using the app and troubleshoot problems". Nadia regarded both online and offline maker activities – the "hands on experience of getting to know the app" and the "engaging offline activities" – as essential for helping teachers decide on the "teaching approach to take when teaching maker projects". Samantha liked the combination of hands-on learning with design thinking, while Sophie favoured hands-on learning as a precursor to team-based makerspaces curriculum planning. Others in the group simply identified hands-on learning as their preferred form of professional learning. Elsewhere, succinct references were made to needing more "expert guidance", "explicit instructions", "time to collaborate" and "peer sharing with colleagues". The use of live webinars was critiqued by several participants (n=4, 14.8%), all of whom felt that these sessions were less helpful than the face-to-face sessions. Nadia explained her criticism by offering, "I think the use of the online webinars could be evaluated. Teachers who were not confident in accessing the notes online, felt a little panicked to complete in between tasks, [and] not all sessions were relevant to getting the project started".

Content, structure and training support were also themes embodied in suggested improvements that participants made. For the six teachers (22.2%) commenting on suggested changes to content, there was a consensus towards adding more supporting resources- as Ella put it, "more detailed instructions on how to use the *Makers Empire 3D* app – for example, info on what all of the controls do as a reference". Kim similarly commented that she would have liked "more actual assistance with the program [*Makers Empire 3D* app], and how to use the functions", whereas Diana suggested that "we could have been shown how to use each tool" and conceded she was "still quite confused about most of the tools and how to use them to make successful designs". For the four teachers (14.8%) commenting on the structure of the program, there was broad agreement that even more "hands-on" time would have been good. Dawn elaborated that she "would prefer more time to experiment with the app... and would like to be shown more ways of changing designs and any additional features the app has to offer", while Rachel stressed the value of having "more hands-on time to explore the app with other staff would help in gaining confidence when using the app and any trouble shoot spots". Six teachers (22.2%) felt that there may have not been adequate support provided during the face-to-face sessions. Madalyn explained that the facilitator "did a great job of trouble shooting, however she is only one person and it would have helped to have a little more support for when tech was not working", while Andrea suggested having "Makers Empire technicians to support [the facilitator]".

## 6.6 Theme 3: Concerns Moving Forward

The final theme included comments from all 27 teachers (100%) on what they felt their concerns were moving forward. For a very large number of participants (n=24, 88.9%), the main concern of interest was collegial support. Almost all the teachers in the sample identified the need for adequate support from colleagues to teach effectively with makerspaces. This support included external colleagues from industry, local IT support within the school, support from teacher "peers" within the school and the broader community of schools, and support from school leaders such as principals and deputy principals. In some responses, the nature of this support was not clearly explained, while in others there was some indication of what the support involved and why it was needed. Industry support seemed to be conceived as outside expertise, such as when Rachel stressed the importance of "engaging with professionals who are experts in this field" and then specifically referenced the name of the Makers Empire instructor running the professional learning. Mackenzie likewise saw the researchers involved in the study as experts, saying that having one of these researchers "on site while we complete the initial lessons is going to be fantastic help to us… with any technical issues… and feedback on our unit as we work through it". Penny felt the best part of her professional learning experience was "having an expert who uses the program to lead us through the app and the design process". Molly said she would like to have further access to Makers Empire experts and the research team "to solve any problems encountered along the way".

Local IT support was described as both a current inadequacy and a future need. As Rachel offered, "IT support to troubleshoot technology problems would be fantastic". Jasmine wanted "an extra pair of hands to help out with technology", while Jenna said she would like "someone to be in the classroom when using the app with students", adding that her "kindy children… will need a lot of one-on-one assistance". Julia simply asked, "where can I ask questions about the app?", while Molly felt that further IT support could be facilitated through the Edmodo community.

In terms of teacher peers and school leaders, Penny stated she would like further “time to collaborate and share ideas”. Amber believed that “meeting with other teachers regularly to discuss how we are going and to have the opportunity to ask each other questions” would help her to be better-equipped, and Sally thought the same of “discussing with peers about problems and successes”. Kim alluded to the value in having professional networks beyond her school community when she stressed the importance of “meeting new people and sharing ideas, including assistance with problem solving”. For Amanda, the main advantage of further professional learning likewise lay in the opportunities to network with colleagues, “so that we can hear about what others have done and ask questions along the way”. However, Amanda also underscored the need to be “supported by the executive at our school, and trusted that what we are doing is not disrupting learning, but rather adding to it”. Abigail believed that she could only be successful if she had “support from my fellow *Makers Empire* teachers, to bounce ideas around and see how everyone is going in the process”. Both Emma and Kirsten emphasised their need for collaboration to meet curriculum demands and programming requirements.

Approximately one fifth of the participants (n=6, 22.2%) specifically referenced problems with technology as a concern they had moving forward. These problems included those that were encountered during the professional learning program, broader technology issues within the school and those they perceived were likely to be encountered while implementing their makerspaces units. For Rachel, the main concerns were “when technology is unreliable… [such as] when the app isn’t working, or when the Wi-Fi is having trouble”. Amber, Tim and Andrea all referenced “technology not working” and alluded to the problems being particularly challenging when there was limited IT support. Madalyn went into further detail, observing that “there have been many issues already with the 3D printers, iPads and computers” and adding that she was “concerned about what will happen when I don‘t have the support we have had during PL sessions”. Corinne conceded at this stage of the project that most “technical issues can’t be known until everyone starts using the software”.

Having adequate resources was an area of focus for 12 teachers (44.4%) in the sample. Across the responses, these resources included professional learning content, teaching and learning materials, and technology infrastructure. For Ella and Diana, the maker stories conveyed in the videos that were presented during the professional learning days were of value, with Ella describing these as “an inspiration” and Diana describing them as reference points for exemplar design projects that show “how successful they can be”. Hannah and Molly both felt they needed access to “refresher” content. For Hannah, this was “continual access to Makers Empire’s newsletters and tutorials”, while Molly said she would like to be able “to go back and view the videos” used in the program. Noting that she was away for one of the professional learning days, Mackenzie was glad that she was able to “access [the] sessions online… and revisit them as needed”. In terms of teaching and learning materials, Kirsten thought that “a cheat sheet with video tutorials would be useful when using the tools”, while Emma stated she would like ready-made teaching resources so that she could “consistently find time to teach these [makerspace] lessons”. Molly, Julia and Alice all had concerns about the infrastructure in their schools. For Molly, the concern was chiefly about “the allocation of resources”, suggesting possible inconsistencies in how well each classroom is equipped for makerspaces. Julia simply worried about “lack of space and storage for resources” in her classroom. Referring to the period following the professional learning program, Alice observed that “It would have been great if we were provided with some ‘loan iPads‘ to ensure that sufficient resources were available to present this program”.

It appeared that teachers at this stage of the project were thinking carefully about how they would support their learners when teaching with makerspaces, as was evident among the references by 11 teachers (40.7%) to this second-order theme. Moreover, this theme emerged as an area of some concern for most of the teachers in this category. Diana and Jane both drew attention to the issue of students designing objects that are not printable, or not practical to print. For Jane, this existed at the ideas stage, where "children's ideas will be too hard to form designs", while Diana was concerned "that it will take too long on their design project on the app, and they will never finish in time". A Year 1 teacher, Sophie was possibly alluding to the same concern when she said that the main challenge for her was "keeping it simple and effective for young students". She further predicted that "that the day to day programming of a school will not allow for the proper amounts of time that this type of child directed learning should have". In terms of specific time on using the app, Penny, Diana, Jasmine and Jenna all expressed concerns. Penny was unsure of "how quickly the students will pick up using the app", while Diana believed it would "take a lot of time to get the students confident about using the app properly". Jasmine believed there could be issues with timing, stating that her students "may take longer to master the skills to use the app before the actual designing process". Jenna pointed out that she was restricted by the number of iPads available to her class.

Finally, for 12 teachers (44.4%) in the sample, coded references to time suggests that having enough time for professional learning, planning, and teaching with makerspaces remained an area of concern moving forward. Rachel and Mackenzie believed that more hands-on time using the app was necessary, with Rachel observing that "more hands-on time with the app for teachers would be great" and Mackenzie feeling "that I haven't had enough time to play around with the app… and I don't understand enough yet". In contrast, Sally appeared satisfied that she "made the time to sit down and have hands-on learning", adding that "I learn better that way". Kirsten and Penny felt more time was needed for collaborating with colleagues and sharing ideas, with Kirsten suggesting that this time would better equip her "to effectively implement this [learning] into our programming".

Specifically not having enough time in the curriculum was a concern named by several teachers that include Sally, Diana, Madalyn, Kirsten, Corinne, Abigail and Emma. Sally regarded the problem as "a very crowded timetable". Madalyn conceded, "I always have concerns relating to time", drawing attention to "a very full timetable, constant extras always being added to the workload, and nothing taken away" and expressing concern "that we don't have sufficient time to dedicate to give this project the full attention it deserves". Corinne was worried that "the day to day programming of a school will not allow for the proper amounts of time that this type of child directed learning should have". Diana, Abigail and Kirsten were concerned about the time that it would take for students to develop sufficient skills. Diana noted "it will take a lot of time to get the students confident about using the app properly", while Abigail felt "that because the software is quite difficult to use (especially for younger children), it may take a lot longer for students to be comfortable with using it by themselves and for them to complete the project". Kirsten simply asked, "How long will it take for students to learn how to use the program?".

## 6.7 Limitations of the Post-Professional Learning Questionnaire

The aim of this chapter was to capture the data from the post-professional learning questionnaire following the completion of the program. However, the post-professional learning questionnaire shares similar limitations to those of the pre-professional learning questionnaire. The range of statistical analyses that could be applied was limited by the overall small sample size, which was likely not as representative of a typical group of teachers as a larger sample would be. The noteworthy gains to confidence and high mean levels of enthusiasm represent a strong finding at this stage of the study; however, with the self-selected nature of the sample, it is possible that these high levels may not be sustained with a larger sample that includes teachers less willing to engage in professional learning and/or teach in makerspaces. Although confidence and enthusiasm were measured using the same sentence stems that were used in the pre-professional learning questionnaire, maker identity, maker values and general technology were not measured, so it was not possible to see if there were significant improvements in these areas.

## 6.8 Post-Professional Learning Questionnaire Analysis: Summary and Concluding Remarks

Despite the limitations noted, the findings from this stage of the study are encouraging, suggesting that participants clearly recognised the value of the professional learning for their future practice, and for their involvement in the project. The high ratings only begin to show any points of difference when they are compared to earlier variables in the pre-professional learning questionnaire – most notably, age, two of the rating items ("I feel confident to teach in makerspaces" and "I feel enthusiastic about teaching in makerspaces") and general confidence with technology. Like the findings from the Edmodo analysis, the professional learning appeared to be particularly well-received by teachers in the mid-stage of their career, especially in the age bracket of 40-49. A further point of interest emerged when considering technology confidence in the three clusters of "Low and Very Low", "Medium" and "High and Very High". Teachers in the "Low and Very Low" clusters showed considerable gain in their confidence to teach with makerspaces, and these teachers were also well represented in the mid-career stage and 40-49 age bracket. As would be expected, teachers in the "Medium" and "High and Very High" levels of confidence were less likely to report large gains in confidence, though these teachers did report, on average, some modest gains. High levels of enthusiasm for teaching with makerspaces appeared to have been sustained throughout the program to date, and this enthusiasm would no doubt play an important role in motivating teachers to engage in further professional learning, problem solving and the sharing of ideas with their colleagues.

At this stage of their involvement in the project, it seemed that participants were engaged in the process of translating their professional learning experiences into future practice. This involved both backwards and forwards orientation in relation to the professional learning program. Thinking back on their experiences, teachers articulated their thoughts on what worked well and what was lacking. Thinking forward, teachers expressed hopes, beliefs and concerns about what might happen in the classroom. They also thought about the steps that they would need to take to effectively implement their makerspaces units of work, with some also candidly revealing doubts about their efficacy. Aside from concerns expressed by some about the perceived limited effectiveness of the web conferencing sessions, all teachers in the sample favourably viewed other aspects of their professional learning experiences. They generally agreed that more makerspaces professional learning in general was needed, with many emphasising hands-on engagement and experiential learning as the best attributes of professional learning. Teachers also articulated gains in both 21st century and technical skills. Closely tied to teachers' professional learning was the perceived need for more time to learn through experimentation with the technology, and the provision of more time for curriculum planning. Curriculum planning was viewed as a logical extension of this program, given that participants started their planning on the second day. Some teachers saw this planning as Stage-based, while others saw it as collaborative in nature. Several teachers believed that opportunities to share units of work, resources and insights would be beneficial to themselves and their colleagues.

While it may not have received the same level of attention in the data as curriculum planning, participants did evidence deeper knowledge of maker pedagogies and the skills that could be developed through effective application of these pedagogies. Several participants accepted the view presented by the Makers Empire facilitator that IDEO's *Design Thinking for Educators* constituted an effective instructional model. Elsewhere, some references to learner-led inquiry and constructivist learning suggested the kind of teaching and learning that participants valued, though it is worth reiterating that since participants usually did not elaborate on what these forms of learning look like in their classrooms, it is difficult to accurately describe their maker pedagogies at this stage in the project. Nonetheless, there did seem to be an observable relationship between the hands-on learning that participants valued in their professional learning and the learning they hoped to see students demonstrate in their classrooms. In terms of skills development, the emphasis on problem solving possibly points to the primary 21$^{st}$ century skill that participants felt they developed in their own professional learning.

# PART III

# Teaching and Learning Implementation

# 7 Lesson Observations

*Researchers observed 31 makerspaces lessons taught by the 24 teachers with teaching roles. A wide range of topics were documented, including designing keyrings, shadow puppets, a habitat for hermit crabs, headphone cable holders, spinning tops, floatable boats, herb markers, playground sculptures, bag tags, and characters to form a stop-motion narrative. Teachers used a mix of online (digital design) and offline (design with physical objects) activities, as well as an assortment of activities involving explicit instruction in some instances and open-ended inquiry in others. Within the lessons, there were high levels of creativity (71% of lessons), design thinking (64%) and critical thinking (58%) observed. Having an appropriate balance of explicit instruction and open-ended inquiry, as well as establishing an authentic problem both appeared to be critical issues in makerspace classes. Object "translation" – where offline objects were translated into online designs and vice versa – emerged as a learning process that appeared to develop critical thinking and problem solving. High levels of student engagement were generally observed in all 31 lessons.*

## 7.1 About the Lesson Observations

In total, 31 lessons were observed by the research team during October and November (Term 4) of 2017. The regular observations involved one visit to the teacher's classroom, and these visits occurred at different points in the unit of work that each teacher delivered. The observation instrument used to document activity while observing the lessons can be found in Appendix 3. The in-depth observations – where three pairs of students' iPad activities were screen recorded – involved three visits for the three teachers concerned. While the standard lesson observations of these lessons are reported here, in-depth analyses of these video screen recordings are reported in greater detail in Chapter 8. The 31 lesson observations were variously timed to occur at beginning-, mid- and end-stage points in the teacher's delivery of the unit of work. Table 7.1 outlines the breakdown of the three periods and the number of observations conducted during these periods.

Table 7.1 – Observation Stages and Classes Observed

| ***Period*** | **Stage** | **No. Observations** |
|---:|---:|---:|
| *10th October – 25th October* | Early | 11 |
| *26th October – 7th November* | Mid | 9 |
| *8th November – 30th November* | Late | 11 |

The research team inductively developed lesson codes to map each lesson to the four domains that researchers used when recording their observations: (1) Student Learning (SL); (2) Learner Engagement (LE); (3) Task Design (TD); and (4) Teaching Approaches (TA). These domains and the codes that relate to each are outlined and briefly described in Table 7.2.

Table 7.2 – Lesson Observation Domains and Related Codes

| ***Domain*** | **Descriptor** | **Related Codes** |
|---:|---|---|
| *Student Learning (SL)* | The observed learning that occurred in each lesson, including students' knowledge and skills development. | Critical thinking; creativity; problem solving; science concepts; authentic learning; inquiry |
| *Learner Engagement (LE)* | The observed learning behaviours that were evident in each lesson. | Collaboration; engagement; risk-taking; autonomy |
| *Task Design (TD)* | The nature, specificity, and scope of the task that was designed, and, where applicable, the unit of work in which the task was set, and how the task was designed to factor in available technology | Offline; online; 1:1; shared iPads; no iPads; team teaching; outdoor makerspace; first time ME use |
| *Teaching Approaches (TA)* | The teacher strategies and pedagogies that underpinned the design and/or delivery of the task. | Open-ended instruction; explicit instruction; Design Thinking; Project-Based Learning; Problem-Based Learning; stations |

## 7.2 Observed Lessons

Table 7.3 shows the detailed summary of each of the 31 lessons observed, organised chronologically in the order in which the observations occurred. To better enable discussion and comparison of themes across the observed lessons, each lesson was given a "working title" (shown in the first column) based on the key content addressed in the lesson and key activities that students undertook.

Table 7.3 – Lesson Observation Summary – Individual Lessons

| ***Name (Year), Lesson Title, Stage*** | **Lesson Description** | **Observed Learning Outcomes / Evidence** | **Key Findings** | **Codes** |
|---|---|---|---|---|
| *Penny*<br><br>*(Yr 1)*<br><br>*Offline Design Stations*<br><br>*Early Stage* | Students worked in "Design Stations" that involved a series of offline (utilising a range of materials such as straw, tape, cardboard, etc.) and online (ME app) activities. Being students' first use of the iPad app, they were relatively free to explore and discover when given time on the iPads. | Students developed problem solving skills and were engaged throughout lesson in each of the stations. Students worked well in groups (especially pairs) and showed self-directedness in their learning. Critical thinking mainly pertained to simple actions with the app, and the students' choices of which materials to use in the design process. | Even though it was their first time using the app, students responded intuitively, and few struggled with using it. The teacher was keen to promote self-directedness ("…we've been working on this all year…") and encouraged students to avoid asking her for answers all the time. The combination of offline and online activities worked well to promote variety, although the big picture around how the activities integrated was not made clear to students. The lesson encouraged open-ended discovery with the app, although the use of stations meant that not all students were doing the same thing at the same time, or in the same sequence. | SL: creativity; problem solving, design thinking<br><br>LE: engagement; collaboration; autonomy<br><br>TD: open-ended; explicit instructions; first time ME use; shared iPads; stations<br><br>Offline and Online |
| *Jenna*<br><br>*(K)*<br><br>*Design a Character!*<br><br>*Early Stage* | Exploring the iPad app for the first time, students learned how to log on, access their account and design a simple 3D character. The teacher modelled an example character that she designed and printed, although there were problems with the legs of the character detaching from the body when removing the material from the base of the design. This prompted a class discussion on possible solutions to the problem. | Students were engaged throughout the lesson and excited to be using the app for the first time. There were some girls who were disappointed that, at least on their version of the app, there were no female characters available to customise. This appeared to affect their engagement with the task. Most students were able to problem-solve with the app. Some students appeared not to distinguish between the character as an abstraction, and as a representation of themselves. This seemed reinforced by a support teacher who asks a student "do *you* want to be a girl?" rather than 'would you like your character to be a boy or a girl?' | Both the teacher's example and the "legs" problem appeared to engage the students well, and they responded to the app intuitively after some minor login issues. While there did not appear to be an overarching reason for creating the characters (for example, a story in which they might feature), the exploratory nature of the lesson led to some interesting, original designs. Students were especially keen to print their designs in a future lesson. | SL: creativity; problem solving, design thinking<br><br>LE: engagement<br><br>TD: explicit instruction; 1:1; first time ME use<br><br>Online Only |

| Name (Year), Lesson Title, Stage | Lesson Description | Observed Learning Outcomes / Evidence | Key Findings | Codes |
|---|---|---|---|---|
| *Kirsten*<br><br>*(Yr 2)*<br><br>*Out-spinning Mr Spinny!*<br><br>*Early Stage* | Students used the Toy Designer feature of the app to design a spinning toy that could spin faster than "Mr Spinny", a teacher model. The teacher demonstrated different approaches to design and, together, the class evaluated how each of the designs could spin. Students then explored the app, ideated possible designs and share them for peer feedback. | Early in their use of the app, students developed technical skills to create, rotate and resize 3D objects in the app. The designs demonstrated creativity – since multiple approaches to creating a spinning object were encouraged – and problem solving, since students needed to consider whether their idea could result in an object that would spin effectively. | One issue to emerge early on was that many of the students simply tried to replicate – in part or in whole – the teacher's model. Since students were still learning the basic elements of Toy Designer, cognitive load and distraction could both be issues; a few students designed objects that did not spin, including characters. Some students also focused on ancillary aspects such as colour. | SL: critical thinking; creativity; problem solving; science concepts, design thinking<br><br>LE: engagement<br><br>TD: explicit instruction; open-ended; 1:1<br><br>Online Only |
| *Diana*<br><br>*(Yr 1)*<br><br>*The Headphone Problem*<br><br>*Early Stage* | Students worked on the "Headphone Problem", a scenario-based task wherein students developed ideas and prototypes to solve the issue of tangled headphone cables in their classroom. Students worked in groups on butcher's paper to ideate possible solutions to the problem. Afterwards, they fed these solutions back to the class, and the viability of each solution was discussed with some reference to 3D printing. | Students demonstrated high levels of creativity, lateral thinking, problem solving as evidenced in the butcher's paper designs, and effective group work in terms of how ideas were recorded, shared and evaluated. Critical thinking was mainly facilitated through the feedback session, where the teacher asked probing questions to ascertain the viability of each design. | The use of an offline precursor to the app and 3D printing so early in the unit of work meant that students' ideas were not mediated by their understanding of what was possible or not possible (and, as a result, there were some divergent and unworkable designs). The teacher was keen on Problem-Based Learning and had taught herself how to implement it. The butcher's paper activity promoted high levels of creativity and, in the class discussion following it, critical thinking. | SL: critical thinking; creativity; problem solving; authentic learning; inquiry; design thinking<br><br>LE: collaboration; engagement; autonomy<br><br>TD: open-ended; no iPads; problem-based learning<br><br>Offline Only |

| ***Name (Year), Lesson Title, Stage*** | **Lesson Description** | **Observed Learning Outcomes / Evidence** | **Key Findings** | **Codes** |
|---|---|---|---|---|
| *Madalyn, Tim and Mackenzie*<br><br>*(K-1)*<br><br>*What to Do with an Empty Tank? (Part 1)*<br><br>*Early Stage* | Students explored the needs and habitat of hermit crabs by considering what kind of house could be built. The problem of an "empty tank" was clearly established, and the hermit crab's survival requirements were explored. After teacher input and concept mapping, students worked on cardboard to sketch possible objects that could be included in the hermit crab's tank. Sketches were presented for discussion. | Students demonstrated critical thinking, because not all designed objects could serve the hermit crab's needs. Lateral thinking and problem solving were also achieved through hypothetical reasoning following the class discussions, and the task was highly authentic because there were real hermit crabs in the classroom. | The use of the problem as a precursor to the design of the hermit crab house meant the task was highly authentic and well-contextualised. Although students did not use the app in the lesson, the activities emphasised lateral thinking, creativity, critical thinking and problem solving. | SL: critical thinking; problem solving; science concepts; authentic learning; inquiry<br><br>LE: collaboration; engagement; autonomy<br><br>TD: open-ended; no iPads; team teaching; problem-based learning<br><br>Offline Only |
| *Alice*<br><br>*(Yr 2)*<br><br>*Whose Keys are These?*<br><br>*Early Stage* | Students worked on "Whose Keys are These?", a Project-Based Learning (PBL) task that involved researching the needs and interests of one teacher in the school and designing a customised keyring to match their personality. During this lesson, both online (ME app) and offline activities (cardboard, ribbon, scissors, etc.) occurred, with the idea that the offline artefact would serve as a prototype for the online/3D-printed model. In the lessons prior to this one, students had surveyed their chosen teacher and documented their needs, interests and background using an inquiry scaffold. | Creativity and critical thinking were demonstrated throughout the lesson as students worked on coming up with a viable design that was informed by sustained inquiry, where they had constructed and delivered questionnaires to better understand their teachers' personalities and interests. The lesson incorporated many of the gold standard PBL elements (for example, voice and choice, authenticity, and challenging problem/question) thus making it a PBL task and prompting the researcher's discussion with the teacher about PBL. | The teacher said she was PBL-trained, having worked at a neighbouring PBL school prior to her appointment at her current school. The lesson was clearly part of a big picture, and the problem of having unidentified keys is addressed in an interesting way. The teacher had also explored the *Makers Empire 3d* app and considered the different ways that 3D modelling and printing might be employed in a meaningful way. The use of a teacher as the object of the survey process meant that there was some original thought needed to design a customised keyring. There was a conscious pedagogical framework underpinning the lesson. | SL: critical thinking; creativity; problem solving; authentic learning; inquiry; design thinking<br><br>LE: engagement; autonomy<br><br>TD: open-ended; explicit; shared iPads; project-based learning<br><br>Offline and Online |

| ***Name (Year), Lesson Title, Stage*** | **Lesson Description** | **Observed Learning Outcomes / Evidence** | **Key Findings** | **Codes** |
|---|---|---|---|---|
| *Ella*<br><br>*(K)*<br><br>*Time to Play!*<br><br>*Early Stage* | After demonstrating a simple toy that she had made, the teacher encouraged her students to open-endedly explore the Toy Designer feature of the app and share their discoveries with the class. Students shared a range of things they discovered, including how to move and resize objects, change colours and delete and restart the design process. Students then had further time to apply the shared discoveries to work on a basic toy design. | Collaboration was evident throughout the lesson, with excited students who were often keen to share their discoveries with both their peers and the class. Although the lesson did not explicitly explore a problem or area of inquiry, students directed their learning through play, interaction with peers and ideas and starting points shared by the teacher. They also demonstrated problem solving to some of the basic problems that the app presents to first-time users (such as correctly resizing and attaching objects). Motivation and engagement were evident throughout. | The lesson suggested that preconceptions about Kindergarten students being unable to learn how to use the app through open inquiry and play are unwarranted. With relatively minimal input from the teacher, many students in the class were able to use the app and create a basic design, simply through experimenting with the Toy Designer feature. At the same time, students could be observed at quite different levels of expertise: some students struggled with their designs while others created elaborate artefacts. | SL: problem solving<br><br>LE: engagement; collaboration; autonomy<br><br>TD: open-ended; 1:1<br><br>Online Only |
| *Madalyn, Tim and Mackenzie*<br><br>*(K-1)*<br><br>*What to Do with an Empty Tank? (Part 2)*<br><br>*Early Stage* | Students built on the previous *What to do with an Empty Tank?* team lesson and designed the layout of the empty tank for the hermit crab. With teacher input, students learned more about the requirements of hermit crabs (heat pad, salt water, bath bowl and food), and how to design a habitat for two hermit crabs. | Students drew well on prior knowledge and could apply this knowledge to important concepts in the lesson. Highly effective group work – with students that were diligent, respectful and collaborative – was evidenced throughout. Critical thinking was also evidenced throughout as students worked on, and critique, their designs. | The lesson effectively built on the previous (Part 1) lesson by allowing students to revisit and extend on important concepts. It was interesting to note that students had two lessons where they have delved quite deeply into the task, but had not yet used the iPad app. This stood in contrast to other lessons observed, where the iPad app preceded the posing of the problem and was mainly exploratory and/or open-ended. | SL: critical thinking; science concepts; authentic learning; inquiry; design thinking<br><br>LE: engagement; collaboration.<br><br>TD: explicit instruction; team teaching; no iPads<br><br>Offline Only |

| *Name (Year), Lesson Title, Stage* | **Lesson Description** | **Observed Learning Outcomes / Evidence** | **Key Findings** | **Codes** |
|---|---|---|---|---|
| *Emma*<br><br>*(Yr 1)*<br><br>*Shape It!*<br><br>*Early Stage* | Students used the Shaper feature of the app to draw and customise simple shapes. Most students finished this task early, and proceeded to less structured exploration of the app. At the end of the lesson, students were asked to share what they have discovered, which included how to resize, rotate and colour 3D objects that were drawn. | Engagement and enthusiasm were evident throughout the lesson. Most students utilised peer interaction and collaboration to learn about the app and share their discoveries. Students that finished early demonstrated creativity through other off-task activities, such as customising avatars. | The lesson provided a suitable balance between explicit, clear instructions and allowing students to direct their learning. However, the task set appeared to be straightforward and relatively easy for most of the students in the class, resulting in the early finish. The teacher recognised this. | SL: creativity<br><br>LE: engagement; collaboration; autonomy<br><br>TD: explicit instruction; shared iPads.<br><br>Online Only |
| *Amanda*<br><br>*(K)*<br><br>*Block the Boat!*<br><br>*Early Stage* | Students used the iPad app to design a boat that will float. The Lesson built on previous lessons where other offline and online designs had been prototyped. Using Blocker, students were relatively free to explore different kinds of designs. After approximately 30 minutes, there was a critical class discussion about the strengths and weaknesses of different designs and hypothetical reasoning about whether they would or would not float. | Students developed lateral thinking, problem solving and creativity through relatively unscripted use of Blocker. Critical thinking was modelled in the class discussion at the end of the lesson. Students appeared to be at quite different points during the lesson. For example, after approximately 20 minutes, some students had designed whole boats while others appeared to have managed only a few lines in Blocker. The teacher appeared to have expertise in dialogic discourse, using it with students to prompt their critical thinking and problem solving during the design process. | Observations indicated that open-ended exploration of the app worked for most - but not all - students. Class discussions played an important role in the development of critical thinking, particularly for Kindergarten (also observed with *The Headphone Problem* lesson). | SL: creativity; critical thinking; design thinking<br><br>LE: engagement; autonomy<br><br>TD: open-ended; 1:1<br><br>Online Only |

| ***Name (Year), Lesson Title, Stage*** | **Lesson Description** | **Observed Learning Outcomes / Evidence** | **Key Findings** | **Codes** |
|---|---|---|---|---|
| *Rachel*<br><br>*(Yr 1)*<br><br>*Making Herb Markers*<br><br>*Early Stage* | Students created both offline (range of materials) and online (*Makers Empire 3D* app) "herb markers" for a garden. The lesson seemed inspired by a *Makers Empire* video that shows how to create herb markers. Approximately 50% of students had iPads, while the other 50% designed their markers offline. The activity was relatively straightforward and mainly utilised explicit instruction, though discussion with the teacher suggested this is intentional, given the class was considered quite "weak". | The offline designs varied widely in shape, size and choice of materials, reflecting both originality and creativity. Some students worked on iPads had their offline prototypes nearby and used these to create a 3D model in the app that resembled the design, thus exercising a degree of critical thinking around how to effectively "translate" a design from one form to another. By the last ten minutes of the lesson, many students had finished and were then dabbling with other activities. | The lesson highlighted design "translation" (where an offline artefact is recreated in the ME app and vice versa). It was not always clear whether this was an intentional process (for example, the teacher wanting students to first design an offline prototype before translating it into ME) or one that was more pragmatically dictated by the availability of iPads (for example, where a teacher creates an offline station for students that do not have access to the iPads for a given lesson, thus they create the offline designs). Here, it seemed involve elements of both. | SL: creativity<br><br>LE: engagement<br><br>TD: explicit instruction; shared iPads<br><br>Online and Offline |
| *Julia*<br><br>*(K)*<br><br>*Build it, Invent it and Make it!*<br><br>*Mid-Stage* | Students worked in one of five stations that included: (1) a building challenge (plan to build the tallest building); (2) invention challenge (create something unique); (3) floating and sinking tests; (4) Lego; and (5) the *Makers Empire 3D* app. Students had approximately 30 minutes on one station. Except for the *Makers Empire 3D* app group, all other activities utilised offline materials. At the end of each 30-minute session, students fed their ideas and creations back to the class for feedback, which was facilitated by the teacher. | Perhaps due to the wide range of activities, students were engaged throughout the lesson. The offline groups who were building and inventing produce some interesting designs that included an interior design of a house and rocket ship. The *Makers Empire 3D* app group learned how to make unusual "lollipop" shapes by combining objects with the Shaper tool, and students showed persistence in working through simple problems that the app presents. | Like other lessons that utilised stations, this lesson promoted engagement by allowing students to respond to different challenges, to use different materials and to create original and interesting artefacts. As such, there were a range of skills in creativity, problem solving and critical thinking that were demonstrated. At the same time, it was unclear as to how the activities fit together, and where they might fit in to the broader unit of work and problem being posed. | SL: creativity; problem solving; critical thinking; design thinking<br><br>LE: engagement; autonomy<br><br>TD: open-ended; shared iPads; stations<br><br>Online and Offline |

| ***Name (Year), Lesson Title, Stage*** | **Lesson Description** | **Observed Learning Outcomes / Evidence** | **Key Findings** | **Codes** |
|---|---|---|---|---|
| *Nadia*<br><br>*(K)*<br><br>*Maker Stations*<br><br>*Mid-Stage* | Students worked in a series of "maker stations", which comprised both offline (range of materials) and online (ME app) activities. Each offline station used different materials (for example, paddle pop sticks, Lego, cardboard/glue), while the online activity involved the teacher "talking through" a ME tutorial as students followed the steps. Students were making a house or improving on a previous design. After approximately 20 minutes, students rotated stations. This lesson was a precursor - for skills development - to the introduction of the problem, which was scheduled to happen in the week following. | Students developed some problem-solving skills and, in the online activity, some basic literacy skills in following instructions. Each station presented different opportunities about what to make and how artefacts could be made, affording a degree of autonomy. Students responded creatively to the challenges, with some interesting and original designs emerging. | In relation to previous lessons, the teacher noted that, when given the choice of which materials they could use, there were some decisions that appeared gendered, with boys gravitating to Lego and construction materials and girls gravitating to cardboard, paint, etc. The teacher noted that it was difficult working with Kindergarten students on the tutorials in the ME app ("there's a lot of stopping to read each step"). | SL: creativity; problem solving<br><br>LE: engagement; autonomy<br><br>TD: explicit instruction; shared iPads; stations<br><br>Online and Offline |
| *Ella*<br><br>*(K)*<br><br>*Will it Float?*<br><br>*Mid-Stage* | Students proceeded to the Outdoor Makerspace, where they tested the floating or sinking properties of a range of objects that included Lego pieces, plastic forks, wooden pegs, stones, and pepper shakers. Using a two-column table on a portable whiteboard, students added their findings to the table. Students were then given playdough and instructed to make an object that can float. When students returned to their classroom, the teacher facilitated a discussion about their findings. | Students demonstrated enthusiasm and engagement throughout the lesson: they were keen to test objects and make designs with playdough that would float. Some students appeared to miss the intent of the lesson, instead focusing on activities such as collecting and distributing water, or the colouring of the playdough when added to the water. Many students were unable to create playdough designs that float. | The lesson represented an opportunity to critically reflect on the importance of failure for success. Although some students appeared to be easily distracted due to the different setting and outdoor activities, they were keen to experiment and test their ideas. The lesson was quite open-ended - further task specificity or scaffolding could have meant more students were consistently on-task. | SL: authentic learning; science concepts<br><br>LE: engagement; collaboration<br><br>TD: explicit instruction; outdoor makerspace<br><br>Offline Only |

| ***Name (Year), Lesson Title, Stage*** | **Lesson Description** | **Observed Learning Outcomes / Evidence** | **Key Findings** | **Codes** |
|---|---|---|---|---|
| *Emma*<br><br>*(Yr 1)*<br><br>*2D Character Creation*<br><br>*Mid-Stage* | Following a class discussion about important considerations when 3D printing, students created a 2D character using the Shaper feature of the app. All students designed characters from scratch, with several examples of works in progress as well as end products shared throughout, and at the lesson conclusion. | All students could follow the instructions and create a simple 2D character. Students demonstrated creativity in their designs, and problem solving with understanding and applying the basic elements of the app. Students also exercised critical thinking in preparing designs that would be possible to 3D print. Students showed self-directedness in their learning having received clear instructions from the teacher, which they followed quickly and efficiently. | The teacher reflected that students were finishing the tasks quickly and efficiently, prompting her to think about how to further challenge them in future lessons. The use of explicit instruction seemed to have played a role in students all being able to achieve the task. | SL: creativity; design thinking<br><br>LE: engagement; collaboration<br><br>TD: explicit instruction; shared iPads<br><br>Online Only |
| *Ella*<br><br>*(K)*<br><br>*Let's Build a Boat (Part 1)*<br><br>*Mid-Stage* | After exploring and discussing basic components of boats, students used the Blocker feature of the app to design a simple boat that "will not fill up with water". Students were given "investigating time", during which, they could experiment with various design ideas. Following this, some students were invited to share their designs with the class for critical friends ("two stars and a wish") feedback. Students had the remaining ten minutes to improve their designs. | All students – including a student who was a first-time user – demonstrated competence with exploring and using Blocker to design boat-like structures. The quality of the designs evidenced critical thinking that followed the discussion about boats and the features that made them buoyant. Some students demonstrated creative flair in their designs, although the connections to boats were not always clear. For example, one student had designed a Japanese Zen garden, while other students became distracted by avatar design during the lesson. | The sharing a design-in-progress process seemed to play an important role in encouraging students to reflect critically on their designs. In turn, these reflections helped others in the class. By positioning the reflection in the middle of the lesson (as opposed to the end), students had time at the end of the lesson to critically apply feedback. This appeared to be a very effective strategy for prompting action-on-reflection. | SL: creativity; critical thinking; authentic learning; design thinking<br><br>LE: engagement; autonomy<br><br>TD: open-ended; 1:1<br><br>Online Only |

| ***Name (Year), Lesson Title, Stage*** | **Lesson Description** | **Observed Learning Outcomes / Evidence** | **Key Findings** | **Codes** |
|---|---|---|---|---|
| *Kirsten*<br><br>*(Yr 2)*<br><br>*Playground Sculpture (Part 1)*<br><br>*Mid-Stage* | With the class divided in two groups, students used either clay modelling or iPads to ideate possible playground sculpture designs. The task was scaffolded to ensure that proposed sculptures were original, that they catered to an audience and had a function. Key stages of the lesson prompted students to reflect on their design decisions and whether they were effective in achieving their end goal. The combination of clay and the iPad app was to assist students in the design process of translating their sculpture ideas into 3D models. | Students demonstrated creativity and individuality in their designs, largely because the task encouraged students to open-endedly explore and design unique sculptures. Some critical thinking was evident in the use of the app, where students explored and worked within the limitations of what they could and could not design with Blocker. There was also evidence of critical thinking among students in the clay group, some of whom realised that they needed to change the base of their structures for greater stability. | The task of creating a sculpture to solve a problem was one step removed from authentic learning, being only a scale model of a sculpture. The teacher commented at the end of the lesson that some students were struggling to know which tools to use in the app and the lesson was supposed to help with that. An important aspect of teaching in makerspaces appeared to be understanding where difficulties might lie and helping students to navigate these through more structured activities through teacher modelling. | SL: creativity; critical thinking; problem solving; authentic learning; design thinking<br><br>LE: engagement<br><br>TD: open-ended; explicit instruction; shared iPads<br><br>Offline and Online |
| *Sally*<br><br>*(K)*<br><br>*Discovery Time*<br><br>*Mid-Stage* | Students were given "Discovery Time", a dedicated time slot during which they worked on a range of offline design challenges. The offline activities consisted of several mini challenges using different materials. For example, students used plastic cups and paper plates to form a tower as tall as possible. Other students created a marble maze using cardboard, paper plates and marbles. These lessons usually occur five times in each fortnight. The teacher also began the lesson by showing a YouTube video of "Rosie Revere, Engineer" to set context around trying hard and not giving up upon failure. | Students developed lateral thinking and problem solving. Creativity was limited to the challenge, with most challenges appearing narrow in scope. Making was limited to the artefacts created in relation to each challenge. | Challenge stations could be good for promoting variety, engagement and basic skills development. It may have been useful to explore how skills developed in activities can be explicitly linked to the problems that are posed in makerspaces units of work. | SL: problem solving<br><br>LE: engagement<br><br>TD: explicit instruction; open-ended; no iPads; stations<br><br>Offline Only |

| ***Name (Year), Lesson Title, Stage*** | **Lesson Description** | **Observed Learning Outcomes / Evidence** | **Key Findings** | **Codes** |
|---|---|---|---|---|
| *Dawn*<br><br>*(Yr 1)*<br><br>*Polluting Pebbles!*<br><br>*Mid-Stage* | During an earlier lesson, students explored the problem of coloured pebbles polluting the water in an outdoor makerspace. In this lesson, students used the *Seesaw* app on their iPads to design the blueprint for an object that could solve or ameliorate this problem. Students discussed and worked with a range of design ideas, including signs, buckets, retaining walls, tunnels and robots. Students drew and labelled their designs, before feeding them back to the class for further discussion and evaluation. Towards the end of the lesson, students had approximately ten minutes to explore the *Makers Empire 3D* app. | Students demonstrated lateral thinking and creativity, producing some very interesting and original design ideas to address the problem. The class discussion enabled critical thinking, wherein the teacher utilised discussion to explore the viability of the proposed designs. Students were engaged throughout the lesson. | The use of *Seesaw* in this lesson – to draw and label proposed designs - was similar to other "offline" lessons that did not utilise the app. Students produced designs, some of which could not be created through the app (for example, a mechanical/electrical robot). However, when used in conjunction with the IWB, *Seesaw* allowed the class to digitally share and archive all the designs. The session with the app at the end appeared disconnected from the design process, with some students not attempting to translate their *Seesaw* designs to 3D designs in the app. | SL: authentic learning; creativity; problem solving; design thinking<br><br>LE: engagement; collaboration; autonomy<br><br>TD: open-ended; explicit instructions; 1:1; problem-based learning<br><br>Online Only |
| *Kim*<br><br>*(Yr 2)*<br><br>*Hawaii and the Puffer Fish*<br><br>*Mid-Stage* | As a class, students had composed a short story about a puffer fish in Hawaii. During the lesson, they worked further on designing a range of objects (puffer fish, trees, etc.) that would be planted into the story with the intention of making a stop-motion animation towards the end of the unit. Since there were not enough iPads for the class, some students worked on creating offline artefacts with playdough. | The lesson conveyed a big picture design problem, since students linked their knowledge/skills/learning back to the story and thought ahead in terms of what would make the stop-motion animation effective. There was some scope for originality and creativity (for example, creating many different species of puffer fish!), though there were limits around creativity, problem solving and lateral thinking beyond the parameters of the story. | The effect on the class appeared to be positive when the teachers was honest about her failures with their students, including when she did not know how to do something. The teacher indicated to the observers that she and other teachers were "struggling to find the problem" when developing/teaching their units of work. This possibly spoke to the relative quality of some problems in relation to others. | SL: creativity; problem solving; design thinking<br><br>LE: engagement; collaboration<br><br>TD: explicit instruction; 1:1<br><br>Online and Offline |

| ***Name (Year), Lesson Title, Stage*** | **Lesson Description** | **Observed Learning Outcomes / Evidence** | **Key Findings** | **Codes** |
|---|---|---|---|---|
| *Hannah*<br><br>*(Yr 2)*<br><br>*Road Safety Bag Tags*<br><br>*Late Stage* | Students designed “safety bag tags” to reflect their understanding of road safety rules. In addition to visuals, each tag had to include one written rule. The teacher prepared a worksheet that guided students through the process and was explicit in her instruction throughout the lesson. During the activity, she checked in with students to make sure they were following the steps. There was a detailed “learning intention” with statements on purpose and criteria for success. | Most students followed the explicit instructions, the result of which was they had developed skills in creating and customising the tags. There was an implied set of skills involved in “translating” the offline designs to online ones, and students seemed to have mastered the app intuitively in a short time. | Explicit instruction seemed to keep all students on task for some time, though in this lesson, it appeared to be about 20 minutes before some students became side-tracked and started working on other unrelated activities. Balancing explicit instruction with open-endedness is a challenge that warrants further investigation in learning design with makerspaces. | SL: creativity<br><br>LE: engagement<br><br>TD: explicit instruction; 1:1<br><br>Online and Offline |
| *Ella*<br><br>*(K)*<br><br>*Let’s Build a Boat (Part 2)*<br><br>*Late Stage* | An opening class discussion encouraged students to constructively criticise a teacher-modelled “flawed” boat design. After discussing some of the problems that would cause the boat in the design not to float, students continued use the Blocker feature of the app to build a boat that they believed would float. The findings from the class discussion – that boats require sufficient walls, enough space and no holes – were explored through students’ designs and discussion during the lesson was facilitated through peer interaction and dialogic discourse with the teacher. | Having identified factors that negatively impact on the buoyancy of boats, students demonstrated some critical thinking by ensuring that their designs have high walls, enough room and no holes. Creativity was limited by the fact that most students designed square boats – objects that rather appeared to be rafts with walls instead of resembling actual boats. Students were engaged and enthusiastic throughout the lesson and appeared keen to ensure they build a boat that would fit the requirements explored in their critique of the “flawed” design. . | The use of a teacher-modelled “flawed” boat design was very effective in this lesson, since it enabled students to critically reflect on failure and generate criteria for success. The three criteria that were identified thus became important reference points for all students as they designed their boat. At the same time, the designs were largely functional, with no attention to aesthetics (that is, the fact that the designs do not resemble typical boats) – thus the authenticity of the designs may be questioned, and this may well have been a limiting feature of the technology at hand. | SL: critical thinking; problem solving; design thinking<br><br>LE: engagement; autonomy<br><br>TD: explicit instruction; open-ended; 1:1<br><br>Online Only |

| ***Name (Year), Lesson Title, Stage*** | **Lesson Description** | **Observed Learning Outcomes / Evidence** | **Key Findings** | **Codes** |
|---|---|---|---|---|
| *Emma*<br><br>*(Yr 1)*<br><br>*Shadow Puppets for the Gruffalo*<br><br>*Late Stage* | Students designed 2D shadow puppets using the Shaper feature of the app. Designs were informed by paper prototypes created in a previous lesson. The shadow puppets were to represent the characters from the *Gruffalo* picture book, and the narrative would be performed using these characters. The teacher created a design scaffold that included the key stages of the narrative and which characters were required for each stage. The teacher demonstrated a 2D design of the Gruffalo and discussed with the class the challenges of ensuring that the design holds together, captures light effectively and can move appropriately when needed. Students spent the remainder of the lesson "translating" their paper designs into 2D models in the app. | Students demonstrated critical thinking in effectively "translating" their designs from paper to 2D models in the app and ensuring that their completed designs would function effectively as shadow puppets. Creativity was limited by the characters in the story and the fact that most students were attempting to create designs that resemble the original illustrations (as opposed to new characters), and the fact that there was overlap in students designing the same characters. Mid-way into the lesson, students could be observed at very different points of progress; some had designed viable characters that could be printed, while others had only produced some disjointed shapes. | Narratives could be a powerful tool for providing context for students' designs. In this case, *The Gruffalo* served as a well-known narrative that the students could bring to life with shadow puppetry, thereby promoting further creativity and play, and adding a performative element to the product. At the same time, when students' designs needed to fit a prescribed narrative, this naturally limited the creative scope of their work. It may have been possible to subvert this with strategies like *imaginative recreation* and *fractured fairy tales.* | SL: creativity; design thinking<br><br>LE: engagement<br><br>TD: explicit instruction; shared iPads; Design Thinking<br><br>Online Only |
| *Kirsten*<br><br>*(Yr 2)*<br><br>*Playground Sculpture (part 2)*<br><br>*Late Stage* | Students worked on the final stages of their playground sculpture model. After approximately 30 minutes of unstructured time working on their designs, several students presented their finished work to the class for feedback. The feedback drew on the scaffold sentence stems that informed the design process (*This is a sculpture of… it is for… it is going to be in the… the problem it solves is…*), and students evaluated both aesthetic and functional properties of each shared design. | Throughout the lesson, there was evidence of critical thinking, particularly in terms of students making connections between model abstractions and their school playground. Designs throughout the class were unique, and though not all students produced models that would translate into functional sculptures, many demonstrated creative flair in their approach to aesthetics. Students presenting their models to the class demonstrated excellent communication skills, and the feedback process appeared to be rich and meaningful. | The lesson – and broader unit of work surrounding it – suggested that there was much to be gained by exploring representational models in the 3D design and printing processes. Even though students only printed miniature models of possible playground sculptures (and it was unlikely that any of these would ever be built), most students were able to make strong connections between the spatial features and requirements of their playground, and the intended, hypothetical aesthetic and functional properties of their model. | SL: critical thinking; creativity; design thinking<br><br>LE: engagement; collaboration<br><br>TD: open-ended; explicit instruction; 1:1<br><br>Online and Offline |

| ***Name (Year), Lesson Title, Stage*** | **Lesson Description** | **Observed Learning Outcomes / Evidence** | **Key Findings** | **Codes** |
|---|---|---|---|---|
| *Madalyn, Tim and Mackenzie*<br><br>*(K)*<br><br>*What to Do with an Empty Tank? (part 3)*<br><br>*Late Stage* | After recapping the living requirements of hermit crabs, students iterated further on their designs for tank accessories, several of which were shared mid-way into the lesson for class feedback. Students then had time to open-endedly explore the app and consider possible ways of adapting their designs-on-paper to 3D models. Their first time using the app, students explored actions such as creating, rotating and resizing simple objects. Some students produced 3D models that resemble their designs-on-paper, while for most students, the latter part of the lesson was mainly a discovery of the app. | Some students demonstrated critical thinking in their use of the app, though many found using it challenging for their first time. Collaboration was problematic, with an "expert" dominating most groups, and the group output being more a product of their work, than of the whole group. Many students were engaged, though some appeared to find working in the large (team-teaching) space challenging. | The lesson showed that having a big picture context around the use of technology remained important, though students still found the technical aspects of *Makers Empire* challenging. Challenging aspects such as resizing, scaling, and joining objects appeared to benefit from explicit teacher guidance. Nonetheless, free exploration of the app can have promoted pockets of expertise that could be leveraged further. Group work using iPads was difficult to manage, and strategies to ameliorate the dominance of individuals may have been necessary. | SL: critical thinking; creativity; design thinking<br><br>LE: engagement; collaboration<br><br>TD: open-ended; team teaching; shared iPads; first time ME use<br><br>Online and Offline |
| *Molly*<br><br>*(Yr 2)*<br><br>*Improve It!*<br><br>*Late Stage* | Students continued designing customised keyring labels for the "Whose Keys are These?" task that was observed earlier in Alice's classroom. The lesson was team-taught by both Alice and Molly. There was an "improve it" scaffold that students used to critically evaluate and extend on previous designs. With 1:1 iPads, students all worked on the app. During the lesson, students encountered further problems such as the ring to attach the label to the keys – for example, what level of thickness was required. | Students demonstrated excellent recall of knowledge and skills, facilitated very well by Alice in the opening class discussion. Both teachers openly conceded they were not experts in using the app, thus instigating teacher-learner partnerships. The designs-in-progress all evidenced high levels of creativity and originality in terms of form, features and aesthetics. Both teachers tried to defer as much as possible to the students when addressing and solving problems. | Makerspaces lend themselves well to teacher-learner partnerships. To some degree, an element of role-play in this lesson was necessary – that is, teachers needed to sometimes pretend they did not know the answer and cultivate a sense of discovery and wonder across the class. This worked well in this class and seemed to suitably align with the team-teaching approach. | SL: critical thinking; creativity; authentic learning; inquiry; problem solving<br><br>LE: engagement; autonomy<br><br>TD: open-ended; explicit instruction; 1:1; problem-based learning; team teaching<br><br>Online Only |

| Name (Year), Lesson Title, Stage | Lesson Description | Observed Learning Outcomes / Evidence | Key Findings | Codes |
|---|---|---|---|---|
| *Samantha*<br><br>*(K)*<br><br>*Does it Really Float?*<br><br>*Late Stage* | Students spent the lesson testing whether their 3D-printed boats would float. After an initial class discussion recapping some of the issues encountered during the design and printing processes, students proceeded to the outdoor makerspace and tested their designs. Approximately 60% of the boats tested floated, which prompted a critical reflection on the properties of successful floating, which included (1) placement of windows; (2) high walls; (3) balance based on inside contents; and (4) resistance to waves, etc. After the testing in the outdoor space, students returned to the classroom and used the ME app to improve on existing designs. | Students demonstrated critical thinking in assessing the factors that affect whether their boats will float. In the iPad activity following, students applied problem solving for the improvement of their designs. | There were noted issues about the time it took to 3D-print objects and to remove the plastic base. Ultimately, the boats were all a similar size and shape, and it was questionable whether all students could correctly identify the factors that would make their boat float or sink and link these to actual scientific principles. | SL: critical thinking; problem solving; authentic learning<br><br>LE: engagement<br><br>TD: explicit instruction; 1:1; outdoor makerspace<br><br>Online and Offline |
| *Amber*<br><br>*(K)*<br><br>*How did you do that?!*<br><br>*Late Stage* | Students tested whether their 3D-printed boats would float. Utilising a bucket of water and teddy figurine, they placed their objects in the water and simulated sea conditions (for example, making “waves”) to see if the boats were buoyant, which was the case for most of the tested boats. Students then used the app to improve and/or reiterate on their designs, utilising dialogic discourse to ask questions like “how did you do that?” and “I need that… how do I get it?” while sharing strategies with their peers. | Students demonstrated critical thinking during the floating/sinking experiment as they identified and manipulated the factors that determine their boat’s buoyancy. They further demonstrated creativity and problem solving when reiterating or improving existing designs. Collaboration was evident throughout the lesson; even though students had their own iPads and were working on their own designs, many students were keen to share problem solving strategies and design ideas. Likewise, students encountering problems were keen to turn to their peers for possible solutions. | The lesson suggested that maker tasks do not have to be designed as “group tasks” to promote collaboration. Moreover, students were happy to reiterate a design even if their previous design floated successfully. Many of these students moved onto exploring more complex features such as the Cogger Tool, although the task could have been increased in complexity to more explicitly allow for this. | SL: critical thinking; authentic learning<br><br>LE: engagement<br><br>TD: explicit instruction; open-ended; 1:1<br><br>Online Only |

| ***Name (Year), Lesson Title, Stage*** | **Lesson Description** | **Observed Learning Outcomes / Evidence** | **Key Findings** | **Codes** |
|---|---|---|---|---|
| *Abigail*<br><br>*(Yr 1)*<br><br>*Making the Three Little Pigs*<br><br>*Late Stage* | Students designed characters from the "Three Little Pigs" fairy tale. There was a scaffolded version of the story that included explicit instructions about what needed to be designed for each stage of the narrative (for example, the pigs, wolf, houses, etc.) and students were working in groups to design all the objects for their section of the story. | The task was relatively straightforward, since students were simply creating standard objects to fit a well-established narrative. Groups of three (and in some cases, four) were working on a single iPad, which meant that some students in the group became off-task. Towards the end of the lesson (note: this was a Friday afternoon), most students in the class were off-task, doing things unrelated to the activity. | The ease of the task and predictability of designs appeared important factors that determined the nature of the designs and the learning outcomes. Exploring how narrative could be reconceived – for example, in utilising "multi-genre response" or "fractured fairy-tale" strategies – in order to promote different interpretations of the story from each group, might have resulted in a greater variety of design ideas to fit their version of the narrative. | SL: creativity; design thinking<br><br>LE: engagement; collaboration<br><br>TD: explicit instruction; shared iPads<br><br>Online Only |
| *Sophie*<br><br>*(Yr 1)*<br><br>*Light Up the Shadow Box!*<br><br>*Late Stage* | Students designed both shadow puppet characters and a shadow box. Using a six-step design process (*ask, imagine, plan, create, test* and *improve*), natural materials and greaseproof paper, students refined their characters and designed the setting for these characters. Students then tested their designs using a lamp to ensure that the shadow box and characters were in proportion, and that the characters cast a shadow. | Students demonstrated critical thinking and problem solving when checking their designs for any attachment problems. The settings drawn on greaseproof paper demonstrated creativity, and students had to exercise further critical thinking when checking for any issues during the lamp test. | An interesting relationship between 2D and 3D emerged in this lesson. One student's chameleon had four legs, with two positioned behind so that the object appears 3D. Similar to other objects like badges and tags, students were also designing what were essentially 2D objects and manipulating them in 3D. | SL: creativity; problem solving; design thinking<br><br>LE: engagement; collaboration<br><br>TD: explicit instruction; Design Thinking; shared iPads<br><br>Online and Offline |

| ***Name (Year), Lesson Title, Stage*** | **Lesson Description** | **Observed Learning Outcomes / Evidence** | **Key Findings** | **Codes** |
|---|---|---|---|---|
| *Jasmine*<br><br>*(K)*<br><br>*Re-Designing Boats*<br><br>*Late Stage* | Students re-designed boats as a way of reiterating or improving designs from previous lessons so that their finished boats float. After initial instruction from the teacher, students proceeded to re-design the boats from scratch. When complete, students shared their new designs with the teacher for feedback. | Students demonstrated some engagement and motivation, with most of the class having acquired the skills needed to effectively design a boat that would float in their work on previous designs. Creativity was limited, with most of the re-designed boats resembling earlier designs. Some students struggled with technical aspects of the app, but most students were now very competent. | The lesson suggested that "re-designing" activities could be useful for consolidating skills and knowledge acquired in previous lessons. However, they could also be limiting if they do not offer opportunities to genuinely extend on prior learning, as was the case with many of the re-designed boats simply reflecting previous designs. The lesson also suggested that teachers might not assume all students have mastered the app. As a late-stage lesson in the unit, there were still some students that struggled with features of the app and would have greatly benefited from peer instruction. | SL: problem solving<br><br>LE: engagement<br><br>TD: explicit instruction; 1:1; online<br><br>Online Only |

## 7.3 Synthesis of Researcher Lesson Observations

From the analysis of each separate lesson and inductive use of codes, frequencies of codes across all 31 lessons were calculated. Table 7.4 shows these frequencies of all positively coded attributes across the four domains, as mapped to the four broad domains and the descriptors for each domain.

Table 7.4 – Types of Learning and Teaching amongst the Observed Lessons (n=31)

| ***Domain*** | **Descriptors** | **Code** | **Frequency (n)** | **Frequency (%)** |
|---|---|---|---|---|
| *Student Learning (SL)* | Demonstrated skills | Creativity | 22 | 71% |
| | | Design Thinking | 20 | 64.5% |
| | | Problem Solving | 18 | 58.1% |
| | | Critical Thinking | 15 | 48.4% |
| | | Authentic Learning | 11 | 35.5% |
| | | Inquiry | 5 | 16.1% |
| *Learner Engagement (LE)* | Observed learning behaviours | Engagement | 31 | 100% |
| | | Collaboration | 14 | 45.2% |
| | | Autonomy | 13 | 41.9% |
| *Task Design (TD)* | Task design and types of making | Online (making with technology) | 15 | 48.4% |
| | | Offline (making with physical materials) | 6 | 19.4% |
| | | Hybrid (Online and Offline) | 10 | 32% |
| *Teaching Approaches (TA)* | Pedagogies, instructional methods, and strategies employed | Explicit Instructions | 24 | 77.4% |
| | | Open-Ended Inquiry | 17 | 54.8% |
| | | Problems | 18 | 58.1% |
| | | Team teaching | 4 | 12.9% |
| | | Stations | 4 | 12.9% |
| | | Project Based Learning | 1 | 3.2% |

From the analysis, five themes emerged, each of which is now explained and discussed.

## 7.4 Theme 1: Level of Task Specificity – Free Discovery vs Explicit Instruction

Most of the lessons observed (n=24, 77.4%) included episodes involving explicit instructions. A smaller majority (n=17, 54.8%) included open-ended tasks with minimal instruction and/or broad direction. Ten lessons (32.3%) utilised both explicit instructions in some places (most usually during the lesson introduction), and open-ended learning in other places (such as the body of the lesson, or at the end when students have finished the main task). Open-ended learning usually presented as discovery, inquiry, and/or play. For example, both discovery and play were employed in four cases (12.9%), such as in *Time to Play!,* when Ella introduced the iPad app for the first time to her Kindergarten class with broad direction for students to explore the features and share what they have learned, or in *Maker Stations*, when Nadia prompted her Kindergarten class to create unique artefacts with materials allocated to different maker stations around the classroom. Elsewhere, learner discoveries were often leveraged by teachers when they naturally occurred, such as in Molly's *Improve It* lesson, where students freely shared both problems and solutions as they were encountered. An example of a typical explicit instruction episode is shown in Figure 7.1, while an example of students engaging in open-ended inquiry is shown in Figure 7.2.

Figure 7.1 – Teacher modelling using a screenshare of her iPad onto the interactive whiteboard

Figure 7.2 – Students completing an open-ended task individually and in pairs

In around a third of the lessons observed (n=12, 38.7%), the open-ended nature of the task focused on creating a prescribed object, but decisions about form, aesthetics, function or audience were left to the students. For example, in *Hawaii and the Puffer Fish*, Kim's Year 2 students constructed and customised different characters that might suit a collaboratively-written class story, while in the *Playground Sculpture* lessons, Kirsten's Year 2 students designed functional and aesthetic models of sculptures intended for their school playground. When open-ended discovery time with the app was utilised as a means of introducing the app early in the unit of work, many of the students appeared able to learn how to use features of the app intuitively. However, allowing students to play with the app without substantive guidance appeared to lead to students across the class being at quite different knowledge stages. This was clearest in five cases (16.1%), such as the final lesson in *What to do with an Empty Fish Tank?* when Kindergarten and Year 1 students from three team-taught classrooms reached quite different stages in their offline to online translation of objects for the hermit crab fish tank. Another example is in *Block the Boat*, where some of Amanda's Kindergarten students were able to produce 3D "boats" using Blocker, while others could only manage a few disjointed lines of blocks. In *How did you do that?!* Amber used peer instruction to support equity in achievement during an open-ended boat design activity, so that those students that were well ahead assisted those that were behind. In *Improve it*, Molly and Alice both explicitly discussed failed attempts (resulting in different points of progress) to customise keyrings with Molly's Year 2 students and drew on the collective wisdom of the class to solve the problems that had arisen.

Clearly observed as a learner behaviour in 13 classrooms (41.9%), autonomy was identifiable where students had the choice about what to make and how to approach making. The degree to which the task utilised explicit instructions often related to other factors such as the nature of the design (as representational, literal or functional), the scope students were given for autonomy, individual creativity, originality and innovation, and the degree to which tasks allowed for designs that were either predictable or unpredictable. For example, in the *Road Safety Bag Tag* lesson, Hannah set the context of the lesson with learning intentions that stipulated exploration for a specified purpose and object ("Today we will continue to explore *Makers Empire* so that we can design a safety bag tag"), while in Rachel's *Herb Marker* lesson, students watched a *Makers Empire* video on making herb markers, and then replicated the steps using both offline and online tools to make their herb markers. In Abigail's *Making the Three Little Pigs* lesson, students created characters and objects that could be inserted into the traditional fairy tale. Each of these three lessons allowed students to design 3D objects, but provided constraints on the designs, leading to what appear to be somewhat predictable outcomes. Similarly, the boat design activities that featured in the lessons of Ella, Samantha, Amanda and Jasmine initially encouraged students to design original and unconventional boats (such as the "crazy boat" design in Figure 7.3), but when combined with other design criteria such as the boat needing to float and be able to be printed with the existing 3D printers, then relatively predictable and uniform, cube-like designs were produced.

Alternatively, in the *What to do with an Empty Tank?* lesson sequence, Madalyn, Tim and Mackenzie encouraged their students to think and design a range of objects that could support the habitat of hermit crabs. While their designs were mediated by discussion and inquiry around the needs of living things, students had more autonomy over what they could design.

Figure 7.3 – "Crazy Boat" Design, Kindergarten Student

By contrast to the less predictable outcomes related to open-ended learning, tasks with a strong focus on explicit instruction tended to result in some students finishing early and engaging in their own discovery with the app. For example, in *Shape it!* And *2D Character Construction*, Emma provided explicit instructions and modelling for her students when forming shapes and manipulating shapes into 2D character designs. Perhaps due to the level of task specificity and simplicity, her students all successfully completed the tasks well within the allocated time. This initially surprised the teacher, who reflectively commented on the need to increase the complexity of future tasks to ensure that all students were both challenged and supported. Concerned about her Kindergarten students not being able to read the tutorial instructions on their iPads, Nadia verbally relayed these instructions to her students, who followed along, and all managed to complete the tutorial. This stood in contrast to Ella's introduction of the app, when she simply allowed students to play and did not appear overly concerned about covering tutorials or basic proficiency (as reflected in the work sample shown in Figure 7.4).

Figure 7.4 – 2D Character Shape (Explicit Instruction), Year 1 Student

Perhaps the frequent use of explicit instructions supported weaker learners – enabling them to stay on task – but may have constrained more able learners, many of whom appeared keen to design other things that are more original and creative than some of the tasks specify.

Interestingly, in five of the lessons observed (16.1%), the set task involved substantially re-designing an object that had already been designed in a previous lesson. The purpose for the re-design was not always clear to the students or observer, and as such, raised the question of how designs could be successfully sustained, iterated, improved and critiqued over the course of the unit of work. This appeared to be a problem when the object could be quickly and easily designed by some students, and was resilient to the additional problems posed, such as in the boat re-design lessons of Ella, Samantha, Amanda, Amber, Jenna and Jasmine. Utilising containers of water, students all tested their printed boat designs to see if they floated, following which they could re-design their boats in the app. For the students whose boats already floated, there were opportunities to explore additional variables such as “making waves”, holding further cargo, identifying factors for success and so on. But in situations where the boat design addressed all the challenges, most of these students appeared to simply re-design their boats from scratch. Kirsten appeared to be conscious of this issue in her *Outspinning Mr Spinny* lesson, where students designed a spinning object that could spin faster than the teacher’s example. This underlying performance factor provided further opportunities to derive motion principles and encourage students to safely compete with one another to produce the “best” design. Overcoming these learning design issues by incorporating similar opportunities for deep, extended learning thus represents a challenge common to many of the classes observed and is a pedagogical strategy that maker teachers could include in their lessons.

## 7.5 Theme 2: Offline and Online Tasks, Sequencing and “Translation”

Table 7.5 shows the breakdown of offline and online lessons observed. Slightly less than half the lessons observed (n=15, 48%) used digital technologies (namely the *Makers Empire 3D* app) and were coded as “online” lessons. Substantially fewer lessons (n=6, 19%) did not utilise technology, coded as “offline”. Around a third of lessons observed (n=10, 32%) represented “hybrid” lessons (coded with both “online” and “offline”), where teachers utilised a combination of “offline” and “online” activities.

In most cases, offline activities involved designing or making objects using standard material such as cardboard, paper plates, cups, paddle pod sticks, sticky tape and playdough. In her *Discovery Time* lesson, Sally provided an assortment of mini challenges that are grouped by stations, while other teachers such as Penny, Nadia, and Alice appeared to use stations to support – and even augment – the online activities that ran concurrently with offline activities. In almost all cases, the online activities involved use of the *Makers Empire 3D* app – the only exception to this being Dawn’s lesson, where most technology use was focused on the *Seesaw* iPad app to prepare and label a 2D design prior to making the 3D version in the *Makers Empire 3D* app. Despite the frequency of combining offline and online activities in the 12 hybrid lessons, it was not always clear as to the purpose for doing so. Often, teachers indicated that offline objects need to be first designed as “prototypes” (such as shown in Figure 7.5), following which, students would “translate” the design into a 3D design using the app. However, the specific sequencing this implied – that is, using the offline activity as a precursor to online design – was not consistently evidenced. In fact, it was common to see groups of students work on both offline and online design activities concurrently in a single lesson, with some students first designing in the app before moving to offline design. Again, it seems to have been determined by the availability of iPads. In most cases, the combination of offline and online activities in a single lesson occurred when there were insufficient iPads for a whole class.

Table 7.5 – Breakdown of Offline and Online Lessons Observed

| **Online (n=15, 48%)** | **Offline (n=6, 19%)** | **Online & Offline (n=10, 32%)** |
|---|---|---|
| Jenna<br>Design a Character! | Diana<br>The Headphone Problem | Penny<br>Offline Design Stations |
| Kirsten<br>Out-spinning Mr Spinny! | Madalyn, Tim and Mackenzie<br>What to Do with an Empty Tank? (Part 1) | Alice<br>Whose Keys are These? |
| Ella<br>Time to Play! | Madalyn, Tim and Mackenzie<br>What to Do with an Empty Tank? (Part 2) | Rachel<br>Making Herb Markers |
| Emma<br>Shape It! | Ella<br>Will it Float? | Julia<br>Build it, Invent it and Make it! |
| Amanda<br>Block the Boat! | Sally<br>Discovery Time | Nadia<br>Maker Stations |
| Emma<br>2D Character Creation | Sophie<br>Light Up the Shadow Box! | Kirsten<br>Playground Sculpture (Part 1) |
| Ella<br>Let's Build a Boat (Part 1) | | Kim<br>Hawaii and the Puffer Fish |
| Dawn<br>Polluting Pebbles! | | Emma<br>Shadow Puppets for the Gruffalo |
| Hannah<br>Road Safety Bag Tags | | Samantha<br>Does it Really Float? |
| Ella<br>Let's Build a Boat (Part 2) | | Amber<br>How did you do that?! |
| Kirsten<br>Playground Sculpture (part 2) | | |
| Madalyn, Tim and Mackenzie<br>What to Do with an Empty Tank? (part 3) | | |
| Molly<br>Improve It! | | |
| Abigail<br>Making the Three Little Pigs | | |
| Jasmine<br>Re-Designing Boats | | |

This observation led to two interesting sub-themes in relation to *translation* and *sequencing* in the task design. Offline-to-online "translation" – where students recreated a design from an offline prototype using the *Makers Empire 3D* app – occurred in five of the lessons observed (16.1%). In the lessons of Emma, Alice, Rachel, and Hannah, as well as the third team-taught lesson of Madalyn, Tim and Mackenzie, the offline prototyping activities all preceded the use of the *Makers Empire 3D* app as a design tool. The team-taught third part of the *What to do with an Empty Fish Tank?* lesson sequence from Madalyn, Tim and Mackenzie was particularly interesting, since these teachers spent most of the unit of work planning and ideating design ideas using offline materials, and only introduced the iPad app towards the end of the unit.

Figure 7.5 – "Offline" Sculpture Modelling with Clay, Year 2 Students


Figure 7.6 – Offline-to-Online Character "Translation", Year 2 Student

## 7.6 Theme 3: The Problem with Problems

During the face-to-face component of the professional learning program delivered in August and September 2017, the *Makers Empire* facilitator emphasised the importance of having a problem to inform the 3D design process. This aligns with common models of Design Thinking, where the initial stages involve discovery and interpretation of a problem before ideating, prototyping and evolving designs that address the problem. Problems form an important component of other instructional models such as Problem- and Project-Based Learning, where real-world solutions provide authentic challenges, prompting students to investigate, propose and/or design possible solutions. Problems also form an integral component in learning theories such as pragmatism, where they can instigate learner-led inquiry and form the bases of cyclical and life-long learning, such that the solution to one problem surfaces new problems and challenges that need to be addressed.

Eighteen of the observed lessons (58.1%) explicitly incorporated a problem as part of the lesson's focus. The problems explored in these lessons broadly fell into three lesson groups. In the first and largest group (n=11, 35.5%), the problems were closely related to typical, real-world issues that promote sustained inquiry and allow for more than one solution. For example, in the *Headphone Problem* (see Figure 7.7) and *What to do with an Empty Fish Tank?* lessons (see Figure 7.8), the teachers focused on problems encountered in the classroom and school, seeking input from students as to how these might be solved in any number of ways. Similarly, the *Outspinning Mr Spinny* and boat building lessons focused on creating toys that would perform functions and could actually be used by the students. In the *Polluting Pebbles* lesson, Dawn posed a problem that occurred in the school (that is, the makerspace being polluted by coloured pebbles) that could easily be linked to pollution problems elsewhere. These lessons all incorporated real world problems (and sometimes real-world spaces, such as the outdoor makerspace shown in Figure 7.9), and in so doing, appeared to promote authentic learning, critical thinking and collaboration.

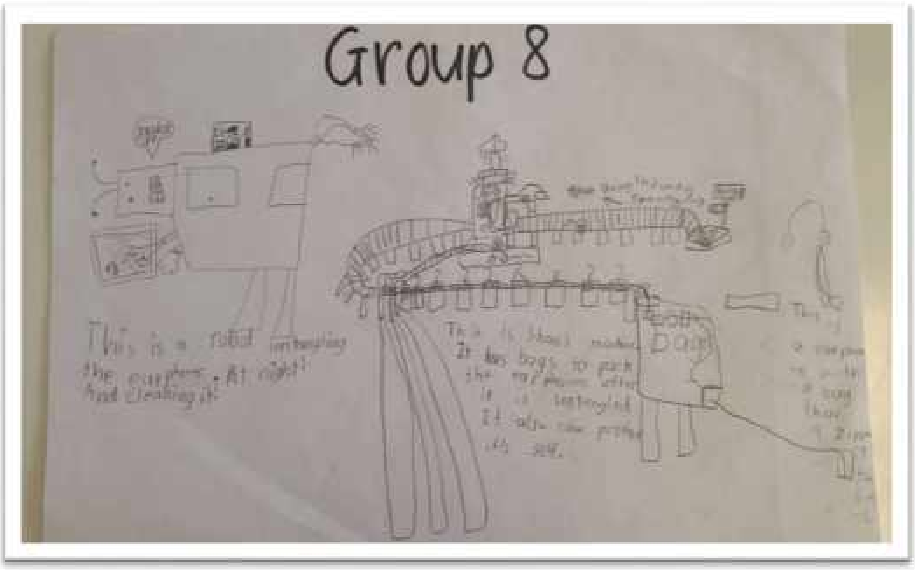



Figure 7.7 – Ideating Solutions to the "Headphones Problem", Year 1 Students

The second, smaller lesson group (n=4, 12.9%) included what are best referred to as the "story" group: *Hawaii and the Puffer Fish*, *Light up the Shadow Box, Making the Three Little Pigs,* and *Shadow Puppets for the Gruffalo*. These lessons all presented the story as a problem "vehicle", particularly with reference to performing each story through different approaches once the 3D objects have been printed. In *Hawaii and the Puffer Fish*, Kim positioned the stop motion animation activity as an end goal that requires the successful creation of characters that could be inserted into the class animation. Similarly, the other lessons in the group utilised a live shadow puppet performance as an end goal requiring the successful creation of the puppets and shadow box. Although the problems addressed in these lessons pertained to a prescribed activity rather than a real-world issue, they still appeared to promote collaboration and problem solving. For example, Sophie's *Light up the Shadow Box* lesson involved considerable trial and error in the production and testing of the shadowbox (see Figure 7.10), while in *Shadow Puppets for the Gruffalo*, Emma produced paper prototypes to prove that it would be possible to print functional shadow puppets in the shape of characters from the narrative.

Figure 7.8 – 3D-Printed Objects for Hermit Crabs, Kindergarten/Year 1 Students

Figure 7.9 – Exploring Things that Float and Sink in the Outdoor Makerspace, Kindergarten Student

The remaining group of lessons (n=3, 9.7%) involved substantive making over the course of the unit of work – but making that was largely an end in itself. In *Herb Markers* and *Safety Bag Tags,* Rachel and Hannah prescribed the object to be created, leaving some of the aesthetic decisions up to the students. Both 3D-printed object types had real-world applicability, with the herb markers being useful in a garden, and the bag tags being useful to identify the owner of the bag while communicating a road safety message. Kirsten's *Playground Sculpture* lessons led to students having a miniature model of a playground sculpture that could be later developed into a real sculpture, and there was obvious applicability to industries such as architecture and urban planning where miniature models are widely used.

Figure 7.10 – Lighting Up the Shadow Box, Year 1 Teacher and Students

Across the three groups, the identified problems varied in terms of real-world applicability, authenticity, focus, and predictability. Some problems appeared real, authentic and challenging, while others were more contrived, straightforward and/or easy to solve. Variability in the nature of problems reflected the ease with which suitable contexts could be applied by teachers in classrooms and was reflected by Kim's words: "myself and other teachers are really struggling to *find* the problem". Teachers also appeared to vary in terms of when and how they introduced a problem to the students. For several teachers (n=5, 16.1%), the problem was introduced at the start of the unit of work and became an important reference point throughout. Elsewhere, the problem was introduced at a later point in the unit, seemingly because the teacher wanted to develop what they saw as prerequisite knowledge and skills prior to students engaging with the problem.

## 7.7 Theme 4: Twenty-first Century Skills and Learning Behaviours Go Hand-in-Hand

Throughout the lessons observed, there was evidence of many of the 21st century skills teachers identified in the pre-professional learning questionnaire – creativity, critical thinking, inquiry and problem solving – being developed. There was also evidence that these skills appeared alongside several learning behaviours that teachers referenced in this questionnaire, including collaboration, engagement, enthusiasm and risk-taking. Most significantly, engagement was observed in all lessons observed (n=31, 100%), and it was rare to see any students off-task for extended periods of time. Creativity was substantively observed in 22 classrooms (71%), where students created artefacts such as objects, plans, and solutions, and where these artefacts clearly reflected original thinking. Genuine collaboration was observed in 14 lessons (45.2%), where students clearly worked together, utilising each other's ideas and skillsets to ensure that what they produce is the product of more than one individual in the group. Problem-solving was observable in 17 lessons (54.8%), where students wrestled with a range of problems, and produced a solution to one or more of these problems by themselves (that is, without the teacher simply presenting the solution to the class, or the solution being specified in the task design).

Not all these skills and behaviours were evident in all classrooms all the time, though there were some notable "starting points", such as the fact that the vast majority of students across all classes were almost always engaged and on-task for most of each lesson. Students regularly voiced their enthusiasm for makerspace lessons, and there was no clear evidence at any time that students would rather be doing or learning something else. The two other behaviours referenced in the pre-professional learning data – collaboration and risk-taking – were less straightforward to observe in the lessons. While most lessons explicitly or implicitly promoted collaboration of one kind or another, there were some noticeable issues with how it played out. For example, when observing iPad sharing between two or more students, it was often possible to see that one student was taking control of the iPad and holding it in such a way that their peers had difficulty seeing the screen and/or interacting with the device. This was particularly noticeable where the teacher had allocated an iPad for a group of three or more students. Risk-taking was difficult to identify but was usually evident when students spoke about their design to the class, the teacher, or the researcher. During these segments of the lesson, some students explained the risks they had taken with unusual designs. Likewise, some students saw the presentation and critique of their designs as a risk in itself.

As noted in relation to the level of task specificity, creativity appeared to be influenced by the extent of creative license that students were given in the task. In many of the offline maker activities, the creativity was mediated by the materials that students were allocated or had selected. Interestingly, some students were observed off-task – for example, when they finished the set task early – and in many of these cases, they were designing other objects or customising their avatars. Critical thinking was most often observed occurring when students had to think carefully about creative decisions, or about how to best solve the given problem so that design criteria were addressed. For example, in Alice's *Whose Keys are These?* activity, students had some creative control over the design of keyring labels, but they had to also exercise critical thinking by ensuring that the labels are customised to suit the needs and interests of the teacher they had interviewed.

## 7.8 Theme 5: Learner-Led Inquiry, Design Thinking and the Big Picture

Sustained, real-world and learner-led forms of inquiry were observable in a small number of lessons (n=5, 16.2%). Occurring at different stages in the observation cycle, it was nonetheless possible in these lessons to see the activity as forming a part of a big picture explored across the unit of work. In *The Headphone Problem*, for example, Diana's Year 1 students engaged with the problem of tangled headphone cords in the first lesson of the unit, thinking laterally and ideating a wide range of possible solutions before investigating the efficacy of each solution, justifying the best solution, prototyping and then making the artefacts during the course of the unit of work. In *What to do with an Empty Fish Tank,* Madalyn, Tim and Mackenzie incrementally introduced content to their students through dialogic discourse, brainstorming and research, and students were prompted to produce ideas at each stage that reflect their current thinking about the habitat and needs of hermit crabs. In *Whose Keys are These?* and *Improve it!* both Alice and Molly positioned learner-led inquiry at the start of the unit and as a precursor to the design process, with students in these classes interviewing and profiling a teacher in their school before using the information to prototype and design a customised keyring for that teacher.

Design thinking was clearly apparent in 20 (64.5%) of the observed lessons. In Diana's lesson, for example, ideation formed the focus of the main activity, while in *Light up the Shadow Box!* and *Shadow Puppets for the Gruffalo* lessons, students followed a six-step process (*ask, imagine, plan, create, test* and *improve*) to design, test and improve an appropriate shadow box for their puppets. Presented in the form of the five-stage IDEO model (*discovery*, *interpretation*, *ideation*, *prototyping* and *evolution*) during the face-to-face component of the professional learning program, teachers in many of the lessons appeared to draw – perhaps unconsciously – on aspects of the model's process, especially ideation, which often took the form of brainstorming on butcher's paper, and prototyping, which frequently took the form of offline making.

Figure 7.11 – "Offline" Making Mini Challenges, Kindergarten Students

In contrast to the lessons with a clearly-communicated "big picture", several lessons (n=5, 16.1%) presented more of a "small picture", which usually appeared in the form of skills-based, mini activities such as the "maker stations" that Penny and Nadia utilised, or the mini challenges that formed the body of Sally's *Discovery Time* lesson shown in Figure 7.11. These were frequently viewed by the teachers as a precursor to the main part of the unit of work. Both Penny and Nadia elaborated that students would be able to build maker skills through the activities, and then apply these skills at a later point in the unit of work when the problem was introduced. Sally's activities formed more of a regular component in the school year, taking place approximately once per week. In all these cases, it was possible to argue that "small picture" lessons built important skills without cognitive overload, and that they engage students in enjoyable, motivating activities.

## 7.9 Limitations of the Lesson Observations

The analysis presented here provides some insight into how task design and the classroom environment interact with student learning and learner engagement. Throughout the observations, task design was relatively easy to identify simply by observing the delivery of the lesson, and examining accompanying materials such as lesson plans, resources and/or the unit of work. Task design also included other clearly-observable phenomena, such as the teacher strategies and pedagogies, the learning environment, and the available infrastructure to support learning. Less visible in the observations were the many manifestations of student learning and learner engagement. Students' learning and their engagement were observed by looking for a range of clues that showed evidence of growth in these areas. For example, work samples were regularly photographed and examined alongside notes to identify cases where students demonstrated critical thinking, creativity, problem solving and autonomy. Similarly, effective learning could be identified by watching class presentations where work was showcased, or by listening to dialogue among students and/or between students and their teacher.

However, given the complexities in any teaching and learning environment, it was not always possible to identify all instances of learning, effective or otherwise. For example, some lessons were not coded with "creativity" because students did not overall demonstrate the same levels of higher order creativity – including originality, flair, and innovation and so on – as other lessons where these forms of creativity were more readily apparent. This did not mean, however, that all students in those lesson concerned were *not* creative. Similarly, "problem solving" was used as a broad code to substantively reflect the lessons where students clearly engaged with an identifiable problem, and produced solutions that were interesting, innovative and original. However, it could be argued that most lessons involved some form of problem solving, whether the problem is a real-world issue, a technical challenge, a posed question, or something else. Therefore, the codes were used in this analysis as generalisation tools that broadly described key aspects of task design, student learning and learner engagement, but they could not ultimately capture everything that occurred in every lesson.

Finally, it must be noted that except for the in-depth lessons that were timed at beginning-, mid- and end-stages of the unit of work, all other observations only involved one visit that occurred at different stages in the data gathering period. As such, the researchers relied on one "snapshot" of learning that may or may not have been consistent with the learning that occurred at other times. Nonetheless, when taken together, these "snapshots" painted a realistic picture of learning and teaching activities in makerspaces across K-2 classrooms in three school settings.

## 7.10 Lesson Observation Analysis: Summary and Concluding Remarks

The main aim of this chapter was to analyse some of the many makerspaces lessons that teachers delivered during the study. Across the 31 lessons observed, the research team noted a wide range of problem-based and real-world topics that engaged and challenged learners. Many teachers skilfully varied the activities, employing both online and offline modes, and balancing explicit instruction with opportunities for open-ended inquiry. Within the lessons, there were high levels of creativity (71% of lessons), design thinking (64%) and critical thinking (58%) observed.

Though some teachers showed a tendency towards either open-ended or explicit forms of instruction, it did not emerge from this analysis that one form was superior to the other, or that either form should have been used exclusively. For example, both Ella and Nadia developed their students' proficiency with the iPad app in quite different ways, with Ella allowing her students to 'play', and Nadia ensuring that her students all successfully complete a tutorial under close supervision. Like other largely open-ended lessons, Ella's students reached different levels of progress while Nadia's all reached the same level. Ella used the different levels of progress as an opportunity for peer instruction, while Nadia used the baseline achievement as a precursor to the main design activity in subsequent lessons. Understanding the relationship between the instruction approach and achieved learning outcomes is key to ensuring that the task design fits the intended purpose of the lesson. In the lessons utilising both explicit instruction and open-ended learning, teachers appeared to leverage the benefits of both approaches while ameliorating some of the limitations.

The delivery of most lessons incorporated a degree of pragmatism as teachers attempted to realise the benefits of learning with makerspaces. For example, the use of learning stations within several lessons suggested that teachers wanted to ensure there was enough variety in the lesson, and that those students who did not have an iPad could still be engaged and challenged in maker activities. In Penny's *Offline Design Stations* lesson, the small number of iPads were allocated to a group of students to use for the duration of the lesson, while other students were working on related offline challenges. Similarly, the use of offline activities by teachers such as Kirsten, Nadia, and Hannah were often viewed as an important part of a design process to balance the use of technology. For example, in the first of the two *Playground Sculptures* lessons, Kirsten divided her class in two, with one half using clay to ideate, and the other class using the app to explore the viability of different designs.

Encouragingly, many students in most of the observed classes demonstrated an ability to simply pick up an iPad and learn, intuitively, how to use the *Makers Empire 3D* app. However, other students struggled, and it could not be assumed that guidance and explicit instruction were unnecessary in all – if any – of these lessons. Emma's strong emphasis on explicit instruction in her *Shape it!* And *2D Character Creation* lessons resulted in some of her students not being sufficiently challenged. In other lessons where explicit instruction was missing, however, students could readily be observed struggling in their use of the app. Several teachers expressed concerns that their young learners were not able to easily learn about the features through tutorials and related activities that require reading substantial amounts of in-app text. An optimal approach for ensuring basic app proficiency at the same time as extending more able learner therefore remains a challenge.

Task "translation" and offline-online sequencing represented an interesting phenomenon emerging from this analysis. Designing an offline artefact using physical materials appeared to cater well to learners that perform trial and error activities more easily when using concrete, offline materials. Similarly, re-creating an offline artefact within the iPad app required critical thinking and problem solving, as students carefully considered how technology affordances could be used to create and manipulate a 3D virtual model of the intended design. Therefore, offline-online translation showed potential to target creativity, critical thinking and problem solving. At the same time, the offline-to-online sequencing appeared to be important for ensuring that the skills were appropriately developed. In the *What to do with an Empty Fish Tank?* lessons, Madalyn, Tim, and Mackenzie all appeared aware of this, making sure that offline discovery, ideation and prototyping all took place before students could use the iPad app. In other lessons, teachers' use of offline and online activities appeared to be more pragmatic in nature, allowing for the available number of iPads and/or need to engage learners in different ways.

# 8 Video Screen Recording Analysis

*Screen and audio recordings were taken from 24 separate episodes of pairs of students working together on the iPads. Across the approximately 16 hours of video analysed, high levels of design thinking were observed, including 52 instances of 'Discovery', 142 instances of 'Interpretation', 219 instances of 'Ideation', 101 instances of 'Experimentation', and 15 instances of 'Evolution'. These were realised through a range of operations in the Makers Empire 3D app, including object creation, positioning, resizing, rotating, joining and rendering. High levels of student-to-student dialogue often occurred, with the teacher having the opportunity to circulate around the class and act as facilitator as required. Extended 3D design tasks – where students iteratively refined their online designs over the course of a lesson or multiple lessons – were not common. Very high levels of engagement were observed in most cases, but in some instances, this could include off-task behaviour relating to the avatar and gamification aspects of the platform.*

## 8.1 Introduction to Screen Recording Analysis

This chapter presents the analysis of the video screen recordings of students' use of the *Makers Empire 3D* app. The procedures that the researchers followed to schedule and record iPad screens are first explained. The section then presents the methodology for the analysis, followed by summaries of each case observed. A discussion of the five first-order themes that emerged during the analysis forms the focus of the analysis in the latter part of the section: (1) *App Feature;* (2) *Design Thinking;* (3) *Dialogue;* (4) *Engagement;* and (5) *Interface Interaction*.

## 8.2 About the Screen Recordings

From the larger sample of participating teachers and students, the research team purposively selected three classes for video screen recordings. Selection was based on three criteria: (1) the teacher's willingness to be involved; (2) the inclusion of one class from every year level involved (Kindergarten, Year 1 and Year 2); and (3) and the inclusion of teachers that the school executive thought would well represent the year group. Within each of these classes, these teachers randomly selected six students to use iPads provided by the research team with the video recording iPad application *AirShou* installed on each. This application runs in the background and, once activated, records all screen activity and audio from the microphone. Selected students' parents had provided consent and these students were aware that their screen was being recorded. Teachers instructed the selected students to work in pairs, where they usually shared an iPad and collaborated on one or more designs during the lesson.

The research team took screen recordings during three visits to each class. The team timed these visits at the beginning, middle and end stages of the unit of work. With three visits and three recordings taken at each visit, the research team aimed to record 27 screen recordings in total. However, technical issues with the iPad application resulted in the loss of two videos from the Year 2 teacher's class (one video lost from the beginning stage, and one from the middle stage). To allow for consistent and objective comparison across the data, the equivalent Year 2 video from the beginning stage was eliminated from the analysis. Nonetheless, the Year 2 videos were significantly longer in duration than the Kindergarten and Year 1 videos, meaning that the overall amount of Year 2 video content examined was still commensurate with the other year groups. Accordingly, 24 screen recordings were included in the final analysis. The breakdown of these recordings is shown in Table 8.1, with reference to the participating teachers and topics studied in the units of work.

Table 8.1 – Video Screen Recording Descriptive Statistics

| ***Year and Teacher*** | **Topic** | **No. Videos / (Total Length)** | | | |
|---|---|---|---|---|---|
| | | Beginning | Middle | End | TOTAL |
| *Kindergarten (Ella)* | Building a Boat | 3 (2:37:40) | 3 (2:18:43) | 3 (0:55:17) | 9 (5:51:40) |
| *Year 1 (Emma)* | Shadow Puppets | 3 (0:36:22) | 3 (1:27:40) | 3 (2:00:31) | 9 (4:04:33) |
| *Year 2 (Kirsten)* | Spinning Toys / Playground Sculptures | 2 (2:21:48) | 2 (1:50:27) | 2 (2:17:45) | 6 (6:30:00) |

Although the research team intended to use the same students across the beginning, middle and end stages, absences and inconsistent use of usernames for logging in meant that it was not always possible to identify the same pairs across these stages. In the case of absences, teachers needed to make some substitutions to ensure the same number of recordings in each class. Despite the inconsistencies, the screen recordings did broadly show the progression in students' knowledge and skills in relation to 3D design, and in some instances showed the development of their 3D objects over the unit of work.

## 8.3 Case Analysis: Charlotte and Polly

From the initial pool of video recordings, two Year 2 videos – (2.3 and 2.6, as summarised in Table 8.4 below) – were selected for closer analysis. Unlike the other cases observed, these videos clearly showed developmental stages of the project that students were undertaking. By contrast, other videos reflected design tasks that were ostensibly contained within individual lessons, and it was not possible to identify earlier or later points of development of the design artefact across lessons in any videos preceding and/or following the video in question. This finding points to the related second-order themes of "ideation", "deletion" and "restarting", as well as the first-order theme of *design thinking*. These themes are further explored in the discussion of themes later in this section.

In lesson 2.3, Charlotte and Polly were tasked with designing a 3D model of a multi-storey house. Their thinking appeared to draw on a clay model that they had produced in a previous lesson, and key pieces of dialogue that were captured in the opening stage of the recording suggested that they were approaching the task with a pre-existing model in mind:

- "Oh – remember we need to have enough space for the garden!"
- "Remember to make it [the door] a different colour so it stands out."
- "Remember – we have to make the furniture bigger!"

Using Blocker, the students efficiently built the perimeter of the house, adding and deleting layers of coloured blocks with precision. They worked collaboratively, appearing to readily adopt each other's suggestions as they proceeded. For example, Charlotte observed that the layers of the wall were "blending well", and suggested, "how about we do it all along the way in that colour?". At 14 minutes into the recording and shown in Figure 8.1, students had produced a model with four layered walls and a door, at which point Charlotte remarked, "Polly – we've done the first level, now all we need is the door!". In turn, Polly recognised the need to delete blocks to form a door, explaining, "I need to minus this one, so I can do that one".

At 15 minutes, the students began to precisely partition the walls of the first level, interpreting the model as they worked. Key pieces of dialogue showed how their interpretations informed further design decisions:

- "This is the dining room."
- "This is the perfect couch!"
- "We need a table… do it red!"
- "I'm doing the kitchen, right?"

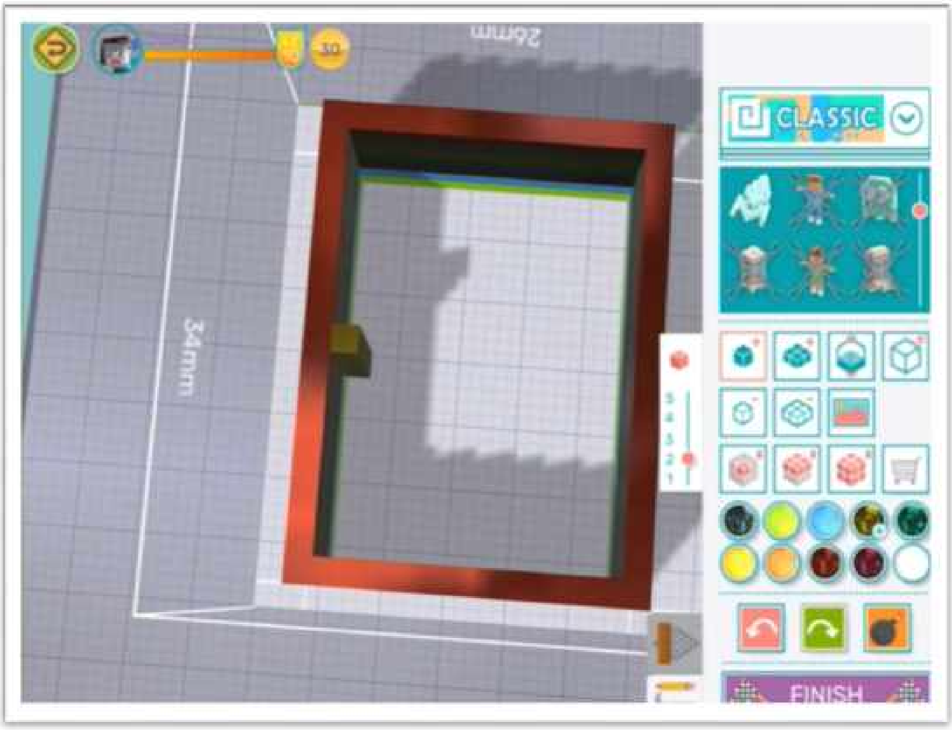



Figure 8.1 – Charlotte and Polly, Layered Perimeter (Video 2.3, 14:00)

At 23 minutes, Charlotte remarked, "we need to do the second level – and remember to make it bigger". Adding a second level to a 3D model house appeared to present several challenges to both students as they interpreted how to best visualise the canvas to see how the second level relates to the first. Unlike the first level, students spent some time adding and deleting possible walls and floors to this level, but Polly observed, "You might do some mistakes, but it's alright, because you can always undo". At 30 minutes and shown in Figure 8.2, students successfully heightened the walls to support a second level, though they appeared reluctant to add the base to this level since this would obscure the furniture and partitioning of the first level.

At this point, the students were becoming flustered. Charlotte snapped, "Polly – don't you know how to use *Makers Empire*?!", while Polly fumbled with the blocks, questioned, "am I doing it wrong?" and added, "it's really hard making the floor!". At 35 minutes, a "Level Up" notification appeared on the screen, and the students were distracted by the avatar customisation screen that appeared. They exited their design-in-progress and began to browse the gallery and shop for other items. Polly was briefly distracted by a diamond wand that appeared in the shop, remarking, "Oh! A diamond wand! How much is that? 18 tokens?". Charlotte pointed out that they "need to return to Blocker", and they returned to their design. At thirty-nine minutes, however, they exited their design and again browsed the gallery, discussing and rating other students' designs. At forty-two minutes, the teacher warned that there was only five minutes remaining in the lesson, and the students then appeared to be searching the gallery for their saved design with the search string "blocker". Appearing to refer to one of her earlier designs, Polly questioned, "why is my one not in the gallery?". Students searched again, this time with the search string "rainbow volcano", without successfully managing to find what they are looking for. Charlotte was frustrated and exclaimed, "Polly – I can't find the one we did!". Shortly afterwards, the teacher closed the lesson.

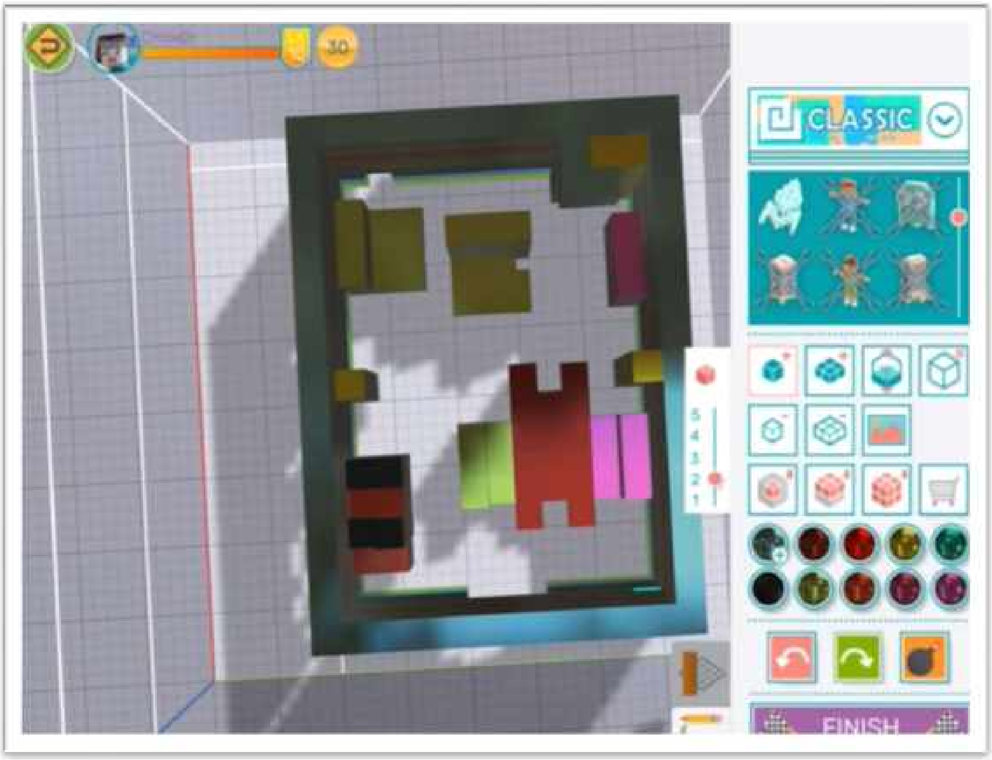



Figure 8.2 – Charlotte and Polly, Furniture and Level 2 (Video 2.3, 30:00)

In lesson 2.6, the students were again using Blocker, this time to build 3D objects that could be added to their model house. Appearing to take into consideration the spatial limitations of the individual design canvas, their perusal of the gallery at two minutes into the lesson revealed that they had already created several objects that could be used. Searching for "flower pot", Polly was unsuccessful in finding the relevant object, and turned to the teacher for help, who stated, "nope – it is definitely there [in the gallery]", before helping her to locate the flower pot design. When asked what they are working on in the lesson, Polly replied, "we're doing separate parts". At five minutes, the students opened a previous design made in Shaper, consisting of a chair with two tables. They made several small adjustments to the positioning of these chairs, before closing the design.

At five-and-a-half minutes and shown in Figure 8.3, Charlotte decided to open a blank canvas in Blocker, prompting Polly to ask, "Charlotte, what are you making?". At this point, the students started speaking quickly to one another in Chinese, and it seemed clear that they were building other furniture that could be added. At 11 minutes, Polly switched to English and remarked, "we don't have an oven!". At 14 minutes, students had successfully built both a couch and an oven, then proceeded to building a tree. Customising the colours and adjusting block size as they went, the students appeared adept in their use of Blocker. Key pieces of dialogue at this stage revealed how they worked collaboratively to ideate and interpret their designs, and how they had developed their skills with the *Makers Empire 3D* app.


Figure 8.3 – Charlotte and Polly, Chair and Tables (Video 2.6, 5:30)

By 20 minutes (shown in Figure 8.4), they had successfully finished the three objects they set out to create.

At 22 minutes, the students shifted course. Polly asked, "what are you making?", to which Charlotte replied, "I'm not telling you!". Making a guess as she observed her partner's progress, Polly said, "a bed? But you can buy a bed!". The students exited the design-in-progress and began to browse the gallery. Finding nothing of interest at this point, they returned to their design and began adding blocks to build a bed. At 28 minutes, Charlotte announced, "Polly – I made that!", and Polly queried, "what about a blanket?". In the five minutes following, the students moved back and forth several times between the design-in-progress and the gallery, appearing to look for similar objects, but finding nothing of relevance. Polly added a different colour layer of blocks to the bed, commenting, "that's the blanket". At 36 minutes, the students again exited their design and continued to browse the gallery. They appeared to be rating and buying each other's designs to generate more tokens. At one point, Charlotte exclaimed "I want this!" while viewing a design of pyramids, to which Polly replied, "but you don't have enough money!" At 41 minutes, the students started taking and "blockifying" photographs of each other, saving them to the gallery before deleting them and repeating the process for several minutes.


Figure 8.4 – Charlotte and Polly, Couch, Oven and Tree (Video 2.6, 20:00)

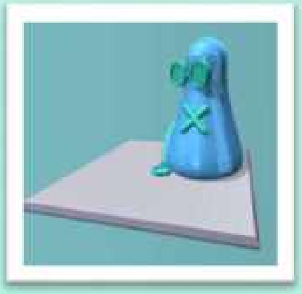
At 47 minutes, the students returned to a blank canvas in Blocker and proceeded to design a swimming pool, first forming the perimeter and then colouring in the interior blue. Polly declared, "I'm going to put a human in there!" and added a Lego-like figure in the middle of the pool. At fifty minutes, they quickly saved their design before the teacher reconvened the students for a 15-minute post-design sharing and discussion session that concluded the lesson.

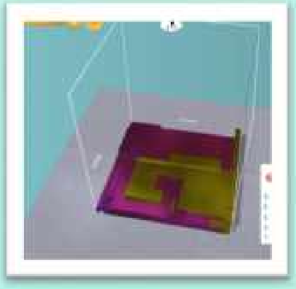
## 8.4 Screen Recording Summaries by Year Group

The three grouped summaries of screen recordings for Kindergarten, Year 1 and Year 2 are presented in Table 8.2, Table 8.3 and Table 8.4 (respectively). Each summary includes information about the lesson focus, timing and stage, and then provides a description of the episodes logged with an accompanying screenshot that shows how far the substantive design progressed during the lesson. Where possible, time indications within the lesson are included to identify turning points and significant moments.

Table 8.2 – Kindergarten Screen Recording Summaries

| ***Video and Lesson Focus*** | **Recording summary** | **Screenshot to Demonstrate Progress** |
|---|---|---|
| *Videos K.1-K.3*<br><br>*Early Stage*<br><br>*Exploring Toy Designer*<br><br>*(Approx. 50 minutes)* | **K.1:** Students began by adding a blob, followed by other objects that include a moustache, glasses and a crown. Although students seemed to have the idea they were building a character, they deleted and recreated objects continually, making limited progress. They also struggled with adding extra objects, and it was not until the teacher intervened and showed them dragging/adding at 16:00, that they worked out how to add several objects at a time. They then proceeded to add, position and delete the objects, restarting the design multiple times and continuing to make limited progress. The teacher demonstrated attaching at around 40:00, and the students seemed to have acquired the concept of this, although they struggled to follow the steps needed. Overall, the students spent the lesson exploring, ideating, deleting and restarting, and seemed comfortable with the idea that they were building skills they could use in subsequent lessons. |  |
| | **K.2:** Working with the Toy Designer feature, the students' initial attempts to make a toy character was slow and unsuccessful, resulting in a series of disjointed objects that do not resemble much. However, at around 20:00, there was a second attempt, and surprisingly, the user managed to quickly and efficiently create a character using a cylinder, moustache, eyes and top hat. It was not clear why this attempt was so quick. At around 25:00, the attempt was deleted and the student then re-created the same character as before. This happened again at 32:00 and 36:00. Each time, the character was quickly re-created and closely resembled the previous design. At 39:00, the student began making colour choices, and then between 41:00 and 50:00, the students appeared to be at the saving screen awaiting feedback from the teacher and instructions on how to save. |  |

| ***Video and Lesson Focus*** | **Recording summary** | **Screenshot to Demonstrate Progress** |
|---|---|---|
| | **K.3:** The student was very quiet for most of the lesson and appeared to be working solo instead of with a partner. After adding a mouth and glasses to the canvas, the student struggled with rotating, positioning and attaching objects. Halfway through the lesson and before the objects are rotated and added, the student pressed the bomb icon and began again with a different coloured blob. The student appeared unsure of where to go next, and the iPad was left dormant for quite a while at 15:00 and again at 35:00. It was not clear at these times what the student is doing – perhaps looking at other students' designs or waiting for further teacher input. The teacher addressed the class at 19:00 and 31:00, asking students to share progress. She also modelled how to rotate objects. For the remainder of the lesson, the student worked with her re-created blob. She was able to successfully create and attach two wings, and almost successfully attached a crown, but decided to delete it. The design culminated in the image depicted in the screenshot. |  |
| *Videos K.4-K.6*<br><br>*Mid Stage*<br><br>*Building a 3D Boat*<br><br>*(Approx. 48 minutes)* | **K.4:** During this lesson, students were instructed to use the Blocker tool to design a 3D boat. With minimal direction from the teacher, students explored possible approaches and experimented with the tool, before strategies were shared in a whole-class feedback session at 21:00-32:00. The students in the video were able to draw a square perimeter for their boat but proceeded to colour the middle in with other blocks, experimenting with colours not appearing to consider the shape of the boat. Students coloured in and form a solid block with different colours. It was not clear that they understood the nature of creating a hollow 3D object that could function as a boat. Even though they received input/assistance from the teacher at 32:30, they're unable to make the object hollow and their efforts result in a solid, tower-like structure that one student referred to as "a flower boat". |  |

| ***Video and Lesson Focus*** | **Recording summary** | **Screenshot to Demonstrate Progress** |
|---|---|---|
| | **K.5:** As with the K.4 recording, students in this recording attempted to design a boat. They appeared to be comfortable with a 2D aerial view of the boat's base and realised at 17:00 that the boat frame should be drawn as a square perimeter and that the area should be filled in to form a base. In the latter part of the lesson, however, students struggled with building a wall, the first main element of working with the design in 3D. As noted with K.4, mid-lesson, students received input from others in the class through a sharing session. By experimenting with rotation and vertical drawing of blocks, students managed to create four walls at 37:00, but the walls had numerous holes. Although there was intervention by the teacher to bring their awareness to this, in the remaining time, they were unable to make a 3D boat with no holes. |  |
| | **K.6:** The students spent most of the lesson exploring possible uses of Blocker with what appeared to be the loose idea that they were designing a boat. One student received a Level 10 level up notification, suggesting he had considerable experience with the tool. At several points in the lesson, however, students stated that they did not know how to design a boat, but this seemed disingenuous given other more complex designs that they showed off in the gallery towards the end of the lesson that they appeared to have designed. Students made very limited progress on their boat design, spending much of the time adding and deleting blocks, and continuing to experiment with building the base and walls of their boat through the five-minute sharing session in the middle of the lesson. |  |

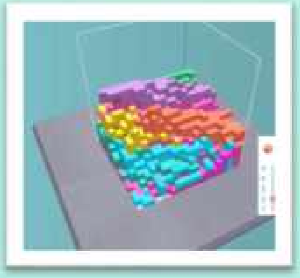
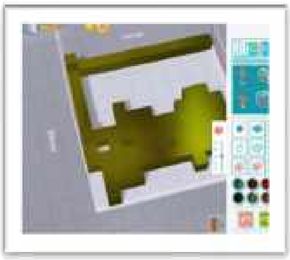
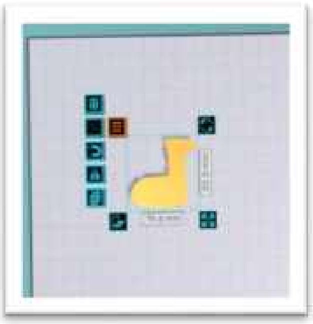
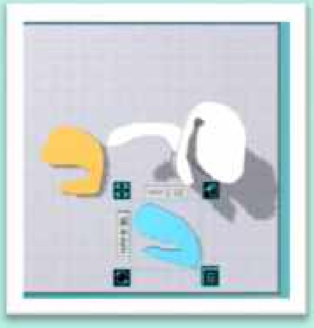
| ***Video and Lesson Focus*** | **Recording summary** | **Screenshot to Demonstrate Progress** |
| --- | --- | --- |
| *Videos K.7-K.9*<br><br>*Late Stage*<br><br>*Building a Boat (Continued)*<br><br>*(Approx. 18 minutes)* | **K.7:** After some initial exploration of the gallery and other features such as their avatar, students attempted to open and continue a boat design from a previous lesson. The design was a solid series of coloured blocks that have been layered but did not resemble a boat. Students added further layers and colours before the teacher reviewed the design at 11:55 and questions whether it was a boat. At 13:00, students attempted to start the design again, but made limited progress in the remaining available time in the lesson. Even though this was a late-stage lesson, the students did not appear to understand the need to create a hollow, 3D boat-like structure. |  |
| | **K.8:** In this lesson, students worked on designing a boat in Blocker. Students struggle with both 2D and 3D representation, adding several blocks to form an object in a messy and random fashion. At around 9:00, students asked the teacher for advice on how to raise the height of objects. At 15:00, after many deletion/restarts, students began to draw something that looks like a perimeter. However, due to the short length of the lesson, they were unable to make much progress beyond this achievement and chose to abandon their design at the conclusion of the lesson. |  |
| | **K.9:** Students began the lesson by exploring different block sizes and colours, and experiment with creating a large base, raising the height to form a solid block (as shown in the screenshot), then lowering the block, deleting and recreating it at several point. They appeared to understand that they needed to be building a 3D boat, but the lesson time afforded limited opportunity, and students therefore spent most of the 17 minutes experimenting with adding and deleting blocks and moving objects randomly around. |  |

Table 8.3 – Year 1 Screen Recording Summaries

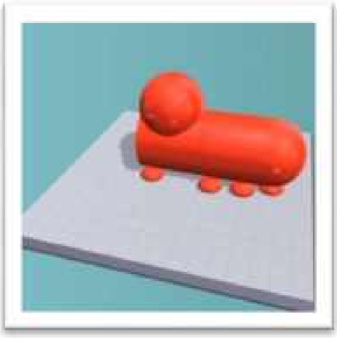
| ***Video and Lesson Focus*** | **Recording Summary** | **Screenshot to Demonstrate Progress** |
|---|---|---|
| *Videos 1.1-1.3*<br><br>*Early Stage*<br><br>*Exploring Shaper*<br><br>*(Approx. 17 minutes)* | **1.1:** In this sequence after logging in, the pair of students used the Shaper tool to create a rectangle, circle, triangle and other shape of different colours and then used the height adjustment toggle to turn each drawn shape into a tower of different heights. Students appeared to have general mastery of platform operation and enjoyed using the tools. The main problems experienced were inadvertently deleting work (not using redo to retrieve) and, at two points, receiving the intersecting lines error message for drawn shapes. The task that was set (draw a shape) was explicitly modelled and easily mastered by students, therefore potentially lacking in challenge. |  |
| | **1.2:** In this lesson, it appeared that students developed skills in the use of the Shaper tool, and they were practising these skills by designing a range of different shapes with the intention of forming a character. Working with a blank canvas, students used the tool to ideate possible "legs". Several attempts reflected the different conceptions of shapes, and students debated the merits of each object they create, deleting and recreating as they go. |  |
| | **1.3:** In this lesson, students experimented with drawing different shapes with the Shaper tool. They successfully created simple shapes that included circles and love hearts, and experimented with resizing, positioning and colouring. However, they did not progress beyond making and deleting singular shapes but appeared confident in having built the skills that they could use in subsequent designs involving more than one shape. |  |

| ***Video and Lesson Focus*** | **Recording Summary** | **Screenshot to Demonstrate Progress** |
|---|---|---|
| *Videos 1.4-1.6*<br><br>*Mid Stage*<br><br>*Creating a 2D Character*<br><br>*(Approx. 29 minutes)* | **1.4:** In this lesson, students used the Shaper tool to construct a simple 2D character by drawing, positioning and attaching several shapes. The students appeared to achieve this relatively easily, and mid-way into the lesson were mostly complete. They experimented further with resizing, colouring, deleting and recreating objects. Students shared the iPad and were happy to contribute ideas together as they worked. There was some evidence of off-task behaviour at 23:00, when students exited the design and engaged in off-task dialogue, but students were otherwise engaged throughout the lesson. |  |
| | **1.5:** In this lesson, it appeared that students were openly experimenting with the Shaper tool, but it was unclear what they were intending to design – perhaps a 2D character similar to the students in Videos 1.4 and 1.6. Students ideated many different shapes including a house, a ghost, the letter G, and a whale. Each of these objects was named as they worked, and students seemed to enjoy creating a shape and then discussing what it might represent. It therefore seemed they were playing with the tool to see what possible objects might be drawn, without fixing on any object or having a specific end goal in mind. They continually deleted and restarted their designs, seeming to enjoy working with a blank canvas and coming up with new ideas throughout the lesson. |  |
| | **1.6:** In this lesson, the pair of students created a 2D figure of a girl. Both students seemed to have this end goal in mind as they worked, and were able to draw, position, resize and colour the objects. They successfully designed the object in layers, adding each of the body parts, discussing their work and remaining engaged throughout the lesson. By contrast to other students, they only occasionally deleted and recreated objects when they felt that the shape they had drawn was not suited to the design they had in mind. |  |

| ***Video and Lesson Focus*** | **Recording Summary** | **Screenshot to Demonstrate Progress** |
|---|---|---|
| *Videos 1.7-1.9*<br><br>*Late Stage*<br><br>*Creating Shadow Puppets*<br><br>*(Approx. 40 minutes)* | **1.7:** During the lesson, students designed a 2D representation of an owl character from "The Gruffalo" using Shaper. They created two circles for the body, a "U" shape for holding the character at the top, arms, legs and a tail. Students appeared to have finished around 20:00 and proceeded to randomly reorder parts of the owl. They became disengaged around 32:00, at which point they exited the design and started exploring the gallery. Students appeared to understand the need to create shapes without intersecting lines. They worked well as a pair and determined the most appropriate shapes to represent their character. The task seemed easily accomplished, and when they completed it around 22:00, there appeared to be no further developments for the remainder of the lesson. |  |
| | **1.8:** In this lesson, students appeared to be ideating possible 2D landscapes using the Shaper tool. Students first added a tree, grass and then a sun by drawing the shapes, resizing, colouring and positioning. Their design was conceived and constructed in stages, and students discussed their progress as they worked. Students finished the first design at approximately 28:00, and then restarted a similar design in the five minutes following. In the final five minutes of the lesson, students became distracted by their avatar screen, and spent the remaining time customising their avatars. |  |
| | **1.9:** Students worked with the Shaper tool to construct their 2D character by designing body parts, through object positioning, resizing and colouring. Students were competent with drawing shapes without intersecting lines and appeared to have the end goal of a character in mind. Students generally stayed on task but were occasionally distracted by avatar customisation options following two level up notifications. |  |

Table 8.4 – Year 2 Screen Recording Summaries

| ***Video and Lesson Focus*** | **Recording Summary** | **Screenshot to Demonstrate Progress** |
|---|---|---|
| *Videos 2.1-2.2*<br><br>*Exploring Toy Designer*<br><br>*Early Stage*<br><br>*(Approx. 70 minutes)* | **2.1:** Students focused on designing a spinning toy similar to the one the teacher demonstrated. During the first 17 minutes, students logged in and watched the teacher demonstrate positioning, resizing, rotating and attaching. The students were working together and appeared to do so throughout the lesson, except for approximately four minutes when one student went to explore what other students are doing. Early in the lesson, they examined the range of objects that can be added in Toy Designer. After adding several objects, including a spinning propeller (as the base), a drainpipe (as the body) and crown (as the head), they seemed to have a clear idea of what they wanted to create and do. They coped well with resizing but struggled with positioning and attaching. The teacher intervened at several places in the lesson – 25:00, 36:00 and 59:00 – and this was mainly to demonstrate further and/or ask students to demonstrate. By 27:00, they had created a simple spinning character with all the parts correctly aligned, and the remainder of the lesson seemed more experimental, where they deleted, re-positioned, re-created and attempted to re-attach objects. |  |
| | **2.2:** Students designed their spinning toy following the initial instructions and demonstration from the teacher. Students seemed to quickly learn the different buttons and discuss how to rotate, position, attach and recolour objects. However, limited progress was made throughout the lesson, and they only managed to create a propeller with a cone underneath (shown in the screenshot). Students appeared to be more concerned about what the different buttons would do and about learning the system rather than making actual progress on their designs. There was a lot of discussion and at-times vigorous debate about what to design. However, there were very few objects added and the design stalls in several places. By the end of the lesson, students had created a very simple spinning toy, which was surprising, given the skills they demonstrated when using the interface. |  |

| ***Video and Lesson Focus*** | **Recording Summary** | **Screenshot to Demonstrate Progress** |
|---|---|---|
| *Videos 2.3-2.4*<br><br>*Mid Stage*<br><br>*Building a House / Playground Sculpture*<br><br>*(Approx. 55 minutes)* | **2.3:** In this lesson, students were very engaged as they built a house with four walls, partitioned rooms and furniture. Students successfully completed Level 1 of the house before attempting to problem-solve how they can add a further level. As they began to add the base of Level 2, they became distracted with elements like the shop and other students' designs. After 35:00, students spent the remaining time browsing the gallery, searching for objects and other students' designs, exploring the shop, etc. Significantly, students did not delete and restart their design, and they appeared at 35:00 to have made considerable progress in their house design. They understood the nature of 3D objects and positioning, resizing, rotating, etc. Using Blocker, they were able to create a simple one-level house with furniture. |  |
| | **2.4:** Students appeared to be working on the initial design of their playground sculpture. They worked together to form an initial structure consisting of a base of several smaller objects holding a larger structure. Students initially experimented with a base of four pyramids holding a large cylinder, before deleting and restarting a design that leads to a base of flattened spheres holding a larger sphere merged with a cylinder. It was not clear from the dialogue or interactions what the object is meant to represent. Mid-way into the lesson, however, students became distracted with the gallery. It seemed clear that students had worked out a way to like each other's designs, generate further tokens for buying designs, and ostensibly buy each other's designs to generate even more tokens. This system distracted students from completing their design and occupied them for the latter part of the lesson. As such, they made limited progress on the initial design, which was perhaps disappointing given the skills they demonstrated with the interface. |  |

| ***Video and Lesson Focus*** | **Recording Summary** | **Screenshot to Demonstrate Progress** |
|---|---|---|
| *Videos 2.5-2.6*<br><br>*Building a House / Playground Sculpture (Continued)*<br><br>*(Approx. 69 minutes)* | **2.5:** In this lesson, students received the instruction to continue working on their playground sculptures. After an initial and brief look at their existing design, the students became distracted by the gallery, examining other students' designs and looking at how many likes they have received. It was fairly clear that the students being recorded has used the *Makers Empire 3D* app a lot and designed many designs. One student was audibly very concerned about how many tokens he had, and he and his peers seemed to discover a system of logging out and quickly logging back in to trade designs to generate more tokens. Students were also distracted by their avatars. At most stages of the lesson, students appeared to be off-task. The design that one student was ostensibly working on was a "soccer playground" sculpture, which appeared to be complete. Although it was opened a couple of times in the lesson, no further work was done on it. Students were nonetheless very engaged in their use of the app and app ecosystem, but otherwise made no progress on their design. |  |
| | **2.6:** In this lesson, students built several objects to add to their house. They successfully built a tree, oven and bed in the first part of the lesson, but became somewhat distracted with the gallery, likes, buying/selling, and taking photos of each other that were "blockified". In the latter part of the lesson, they refocused on their task and added a swimming pool. Students also spent parts of the lesson discussing how their objects might be organised when they are 3D-printed, and what other objects could be designed to add to their house. |  |

## 8.5 Analysis of the Screen Recordings

The analysis of the video screen recordings occurred in two stages. Stage 1 involved logging each action sequence or piece of dialogue as an *episode*. Stage 2 involved the addition of these logs to *QSR NVivo* (Version 11) for inductive coding.

When preparing the video logs for Stage 1, time stamps were used as a reference point, and episodes were described in shorthand as single lines in a *Microsoft Word* document. To determine the start and end points of each episode, the research team examined individual actions, sequences of actions, and pieces of dialogue to establish the main intention of the user at that time. Pauses in the videos were also closely examined, since they often indicated the end of one episode and starting point of another. Some episodes contained one action or piece of dialogue, whereas other episodes contained more than one action sequenced together and/or more than one piece of dialogue. In some cases, actions and dialogue occurred at the same time, and were therefore captured as the same episode. In total, the research team logged 1208 episodes across the 24 videos analysed.

Logged actions often involved the use of verbs that summed up how the students were interacting with the *Makers Empire 3D* app. For example, if a student was moving an object around the canvas, the action was logged (and later coded) as “positioning”, whereas if a student was adjusting the size of an object, it was logged (and later coded) as “resizing”. Beyond establishing the primary action or sequence of actions, the research team did not log further levels of detail such as “moving left”, “touching an object”, “moving right”, “swiping downwards with finger” and so on. The main purpose in this stage was to succinctly capture the actions taking place on the screen and categorising them in terms of the observed main uses of the application. Dialogue was usually logged where it could be clearly heard, and where it had some recognisable relationship to the actions taking place on the screen. Representative and pertinent dialogue was often typed out verbatim, to provide accurate illustration of student discussion. Later, the “student-student” code was inductively determined for student dialogue, while the “teacher-student” code was determined for dialogue between the teacher and individual student. Given the limitations of the microphone and the prevalence of ambient noise, not every piece of dialogue could be captured. The research team therefore had to focus on what was heard, and whether this pertained to the actions occurring on the screen.

In Stage 2, the research team explored the video logs inductively through segmenting, coding and the creation of a category system of first- and second-order themes. Although each episode was coded separately, multiple codes were most often used to describe the episode. For example, the episode “Draws base of boat, deletes, draws wall, deletes” broadly described attempts to build the initial frame of a 3D boat, and was coded with the nodes “object creation”, “ideation” and “deletion”. The use of multiple codes thus reflected the different perspectives of each episode and ensured that the data could later be viewed through each perspective as needed.

Table 8.5 shows the category system that emerged through inductive analysis. The research team developed five first-order themes, including: (1) *App Feature*; (2) *Design Thinking*; (3) *Dialogue*; (4) *Engagement;* and (5) *Interface Interaction*. Column 2 (Number of Coding References) provides an indicator of the frequencies with which the themes occurred in the data, while Column 3 (Number of Words Coded) provides an indicator of the level of detail provided across the responses. The first-order themes and their corresponding second-order themes are discussed in the following sub-section.

Table 8.5 – Coding of screen recordings

| ***Code*** | **Number of Coding References** | **Number of Words Coded** |
|---|---|---|
| ***1. App Feature*** | 28 | 139 |
| *App Feature\Blocker* | 9 | 28 |
| *App Feature\Shaper* | 13 | 52 |
| *App Feature\Toy Designer* | 6 | 59 |
| *2. Design Thinking* | 534 | 5,449 |
| *Design Thinking\01 Discovery* | 52 | 531 |
| *Design Thinking\02 Interpretation* | 147 | 1,624 |
| *Design Thinking\03 Ideation* | 219 | 1,893 |
| *Design Thinking\04 Experimentation* | 101 | 1,235 |
| *Design Thinking\05 Evolution* | 15 | 1,660 |
| ***3. Dialogue*** | 339 | 3,868 |
| *Dialogue\Student-Student* | 240 | 2,531 |
| *Dialogue\Teacher-Class* | 43 | 619 |
| *Dialogue\Teacher-Student* | 56 | 718 |
| *4. Engagement* | 150 | 2,004 |
| *Engagement\Excitement* | 83 | 694 |
| *Engagement\Off-Task* | 40 | 1,091 |
| *Engagement\Problems* | 27 | 219 |
| *5. Interface Interaction* | 602 | 5,049 |
| *Interface Interaction\Aesthetics* | 60 | 584 |
| *Interface Interaction\Attachment* | 6 | 37 |
| *Interface Interaction\Deletion* | 69 | 436 |
| *Interface Interaction\Exploration of Platform* | 39 | 833 |
| *Interface Interaction\iPad Keyboard Login* | 15 | 170 |
| *Interface Interaction\Level Up Notification* | 26 | 117 |
| *Interface Interaction\Object Creation* | 193 | 1,610 |
| *Interface Interaction\Positioning* | 60 | 416 |
| *Interface Interaction\QR Code Login* | 6 | 32 |
| *Interface Interaction\Resizing* | 34 | 254 |
| *Interface Interaction\Restart* | 51 | 329 |
| *Interface Interaction\Rotation* | 43 | 231 |

## 8.6 Theme 1: App Features

Of the five themes emerging during the analysis, Theme 1 pertains to the app feature that formed the focus of the lesson. For efficiency, the research team coded the title of the lesson in the video logs with the feature concerned. Although most lessons only focused on one feature alone, some lessons – particularly those where students engaged in off-task behaviour and/or open exploration – involved the use of more than one feature. Shaper was the most common feature used (11 lessons), followed by Blocker (9 lessons) and Toy Designer (6 lessons). Students appeared to exclusively focus on the tool/feature that was prescribed by the teacher, with the only exceptions observed being in Lesson 2.3, 2.5 and 2.6, where students briefly switched features when opening and making minor adjustments to previous designs.

## 8.7 Theme 2: Design Thinking

The lesson observation analysis included reference to students' design thinking skills, as a singular concept, where some development of these skills was identified in the lessons observed. However, given the focus on learning and teaching more generally in that analysis, individual stages of design thinking, or the specific stages of the IDEO Design Thinking model did not clearly emerge as second-order themes. By contrast, with its focus on individual actions within the Makers Empire interface, actions in many of the screen recordings more clearly reflected individual stages from the IDEO model, and the use of each stage as a separate code helped to describe and rationalise some of the ways that students interacted with the application interface. The first three stages of this model (Discovery, Interpretation and Ideation) were strongly evident, while the final two stages (Experimentation and Evolution), though less evident, were also reflected. Table 8.6 shows these stages alongside common actions and example dialogue that were coded for each stage.

As the actions and dialogue outlined in Table 8.6 suggest, the stages of the IDEO model were evident in both students' interface actions, as well as student-to-teacher and student-to-student dialogue. *Discovery* reflected the exploratory nature of students' engagement with different parts of the *Makers Empire 3D* app. Actions commonly included rotating, panning and zooming to gain different viewpoints of designs, browsing and searching the gallery to examine other students' designs, and exploring other parts of the app platform, such as avatar customisation options, or the buying and selling of designs. Dialogue very often included questions posed to the teacher and peers, with occasional statements about things that students were looking for and hoping to find. *Interpretation* often reflected students' reasoning as they worked, embodied in actions such as rotating, panning and zooming the canvas to understand the design-in-progress, discussing object representation with peers, recognising and naming objects, identifying and solving problems, and determining next steps in the design process. Key pieces of dialogue at this stage typically included questions and statements about what was happening on-screen as designs were unfolding. *Ideation* reflected students' interest in creating and ideating different aspects of the designs-in-progress. Key pieces of dialogue that reflected ideation included suggestions about what to do next, statements about what individual students are doing, and suggestions about what to delete. Building on *Ideation*, *Experimentation* involved manipulating embodied and established ideas. Key pieces of dialogue typically included students' descriptions of how and why they were manipulating objects. Finally, *Evolution* reflected students' arrival at a semi-complete or fully-complete object and involved saving and naming these objects in the application gallery, as well as presenting them to peers. Dialogue at this stage was often declarative in nature, such as when students stated a name for their design or declared to their teacher that they had finished.

Although there was ample evidence of many aspects that inform the first three stages of the IDEO model being addressed in students' interaction with the *Makers Empire 3D* app, Stage 4 (*Experimentation*) and Stage 5 (*Evolution*) were somewhat more problematic. According to the model, Stage 4 typically involves students selecting one idea from the ideation stage and developing it further into a working model alongside other prototypes such as storyboards, diagrams, mock-ups and/or role-plays. Prototyping also often involves the presentation of a working, complete model for peer feedback, and the collation of feedback learnings that students can use to refine the model.

Table 8.6 – Design Thinking Coding – Common Actions and Example Dialogue

| *Design Thinking Stage* | **Common Actions:** | **Example Dialogue:** |
|---|---|---|
| 1. *Discovery* | • Rotating canvas<br>• Panning/zooming canvas<br>• Browsing available objects<br>• Browsing other students' designs in the gallery<br>• Searching for specific designs in the gallery<br>• Copying other students' designs from the gallery<br>• Buying and selling designs<br>• Exploring the app platform | • "How do you press these buttons?"<br>• "Glasses… where are the glasses?"<br>• "How do you make a boat?"<br>• "How do you make it big?"<br>• "Oh – how much is that diamond wand?"<br>• "Where is my design [in the gallery]? I can't find it!"<br>• "What do you want? Tell me and I'll get it for you"<br>• "How do you spin it?"<br>• "How do you change the background? |
| 2. *Interpretation* | • Rotating canvas<br>• Panning/zooming canvas<br>• Discussing representation<br>• Recognising and naming objects and/or components of objects<br>• Identifying and solving problems encountered<br>• Identifying next steps, such as needed components, or design decisions | • "What just happened?"<br>• "Now it's working again"<br>• "That's a body… we need a head"<br>• "That's your boat, isn't it?<br>• "That looks like a…"<br>• "You put the face all green!"<br>• "I need to try to work out how to turn around the wings"<br>• "You got the measurement!"<br>• "The wing keeps moving!"<br>• "I need to minus this one, so I can do that one, ok?" |
| 3. *Ideation* | • Object creation<br>• Project deletion and/or restart<br>• Object positioning<br>• Object resizing<br>• Object attachment<br>• Object colouring | • "Let's do your one"<br>• "Make it bigger"<br>• "Turn it round"<br>• "Make it green"<br>• "I'm going to double this"<br>• "Let's do a potato head"<br>• "Make it a different colour so it stands out"<br>• "I have a better idea, but we'll have to delete this one [and start again]" |
| 4. *Experimentation* | • Object deletion<br>• Object re-creation<br>• Object repositioning<br>• Object resizing<br>• Object attachment<br>• Object colouring | • "This shape is better than that one – switch them"<br>• "Maybe I'll make it a bit smaller, so it can fit"<br>• "Press the bomb and make it again!"<br>• "I will turn the crown like this…" |
| 5. *Evolution* | • Saving objects<br>• Naming objects<br>• Presenting objects to peers | • "Call it Shiny Eel Rainbow Racing Track!"<br>• "Miss A, I'm finished!"<br>• "It's called *Soccer Playground*, and my friend bought it". |

In Stage 5, model refinement occurs alongside the initial measurement of the design's impact on the community. In the video screen recordings, students appeared to focus mainly on discovering what is possible, interpreting what they do within the app platform, and generating many ideas. Rather than focusing on refining a working model, the 101 coded instances of experimentation were mostly superficial, limited to manipulating conceptual ideas and occasionally drawing on offline prototyping for guidance and inspiration. Students were still in the process of developing working models, with some only occasionally presenting initial works-in-progress, and not having progressed to the point where a working model could be refined through collated feedback. Likewise, the 15 coded instances of Evolution were superficially limited to students perceiving task completion and sharing their completed 3D designs with the class via the online gallery, or occasionally in a face-to-face presentation session. The research team did not observe attention being given to measuring the impact of completed designs on the community, or on refining models through community feedback, though this finding may well have simply been a limitation of what was able to be captured in the recordings.

## 8.8 Theme 3: Dialogue

Among the 332 pieces of recorded dialogue, the majority (n=233, 70.2%) was student-to-student. Captured dialogue in this category typically consisted of questions, observations and stated intentions. In most cases, dialogue occurred as students worked on their designs. The word cloud shown in Figure 8.5 depicts the most commonly used words in the dialogue. These words are further explored Table 8.7, which shows the frequency of common words and their related synonyms. Common words such as "make" emphasised the designs and parts thereof that were recorded. Words like "need" reflected students' interest in completing what they saw as required actions. Other words such as "first", "going", "done" and "now" were time references that indicated where students saw themselves in the design process. Words such as "look", "turn", and "see" reflected students' interest in interpreting what they saw in the design as it unfolded.


Figure 8.5 – Student-to-Student Dialogue (Word Cloud)

Table 8.7 – Student-to-Student Dialogue – Most Common Words Captured

| ***Word*** | **Count** | **(%)** | **Similar Words (Referenced Elsewhere in the Data)** | **Example of Captured Dialogue** |
|---|---|---|---|---|
| *make* | 85 | 4.83 | build, building, clear, creates, draw, draws, fix, get, making | "I'm trying to make a boat" |
| *need* | 46 | 2.76 | ask, asking, asks, need, needs, takes, taking, want | "I need to work out how to turn around the wings" |
| *look* | 33 | 2.10 | appear, appears, face, look, looks, search, see, wait | "That looks like a flower boat" |
| *turn* | 31 | 1.55 | bit, bits, going, , round, turn, turning, turns, work, working | "See – I'm turning it!" |
| *level* | 30 | 2.22 | even, flat, floor, level, levelled | "Now you're on Level 8!" |
| *get* | 29 | 0.72 | begin, find, fix, get, going, grow, receives, start | "What do you want? Tell me and I'll get it for you" |
| *like* | 26 | 2.02 | like, liked, liking, wish | "I got 28 likes!" |
| *design* | 26 | 1.74 | designing, designs, name, project, show | "What do you want to call this design?" |
| *draws* | 22 | 0.79 | drag, draw, draws, get, line, pass | "You can draw everything" |
| *want* | 21 | 0.83 | missing, want, wish | "No – not that… I want to do a house" |
| *one* | 20 | 1.58 | one | "I need to make another one" |
| *start* | 18 | 0.48 | begin, going, part, start, starting, starts | "You're starting all over again?" |
| *know* | 17 | 1.20 | bed, experiment, know, knows, live, love | "I don't know what to do" |
| *colour* | 16 | 1.27 | colouring, colours | "Make it green" |
| *now* | 16 | 1.27 | now | "…done the first level… now all we need is the door!" |
| *first* | 16 | 0.63 | begin, first, start, starting, starts | "You need to shrink it first" |
| *working* | 16 | 0.45 | going, shape, shapes, work, working | "I'm trying to do this, but it's not working!" |
| *let* | 15 | 0.85 | allow, get, let | "Let me draw it" |
| *around* | 14 | 0.99 | around, round | "How do you turn this around?" |
| *blocks* | 13 | 0.98 | block, blocks, forget | "How do you make the blocks bigger?" |
| *see* | 13 | 0.45 | control, find, picture, project, see, viewing | "You have to do this, so we can see it properly" |
| *move* | 12 | 0.70 | going, move, moves, touch | "Let's move it like this. Look – it's flying!" |
| *delete* | 11 | 0.87 | delete, deletes | "You need to delete it. I don't want it anymore" |
| *boat* | 10 | 0.79 | boat, boats | "That doesn't look like a boat, actually" |
| *going* | 10 | 0.28 | blending, exits, going, leave, live, pass | "I'm doing to build a human in here" |
| *change* | 9 | 0.71 | change, changed, changes, changing | "You have to change the angle of the computer" |
| *trying* | 9 | 0.71 | attempting, try, trying | "I'm trying to help you!" |
| *shape* | 9 | 0.30 | build, building, shape, shapes | "Let me try – what shape do you want?" |
| *buy* | 8 | 0.63 | buy, buying | "Are you done? Can we buy it?" |
| *done* | 8 | 0.63 | done, did | "Just press it and you're done" |

Captured pieces of dialogue between teachers and students (n=56, 16.5%) revealed that questioning was often used by students when they are stuck. Students most commonly asked their teacher using question stems such as "how do you…?", such as when students in Lesson 1.7 asked their teacher, "how do you draw a shadow?", or when students in Lesson 2.1 asked, "how do you make it bigger?". Students generally seemed to accept their teachers as more knowledgeable than themselves with the application. On the other hand, teachers' use of questioning suggested they were trying to encourage students to think their way through a problem, as evident in the following captured statements:

- "Let's have a think… how do you think you could you move this crown?"
- "What are you making?"
- "What have you done so far?"
- "Can you make it a bit taller?"
- "I like those shapes. Why don't you fill them in?"
- "If you don't like that step, what could you do?"
- "What would you like to call your character?"
- "Can it [the object] stand by itself? How do you know?"
- "Have you got wings attached?"
- "Is it going to be strong enough?"
- "Do you want to start again?"
- "Great – is that the owl?"
- "What other shapes could you use?"
- "Can I see how this compares to your drawing? What are the differences?"

Less common were teachers' judgments of students' work. Instead, teachers tended to emphasise students' abilities and provide encouragement, such as when Ella remarked to one of her students, "I knew you'd be good at that", or when Kirsten said, "I like the way you're putting the shapes together" to one of her students.

Although it was not the focus of the screen recordings, the research team was able to capture some dialogue between the teacher and the whole class. For the most part, this included teachers' instructions at key points in the lesson, as well as time-based prompts throughout the lesson. Both Kirsten (Year 2) and Emma (Year 1) could be heard modelling steps, such as when Emma remarked, "just watch me first, and then you'll get to play with it", or when Kirsten stated, "I'm just going to show you how to use these buttons". Elsewhere, most of the lessons included a sharing session either mid-way into the lesson, or at the end. During these sessions, the teachers could be heard asking the students, for example in Emma's words, to "share what you have done, and why you've done it, so that we can get ideas on how to improve our designs". Kirsten similarly instructed her students to listen to "find three people that did cool things, so you can ask them about their designs".

## 8.9 Theme 4: Engagement

Excitement was often evident in the captured dialogue. Students commonly expressed their excitement about a range of elements within the broader application platform, including level up notifications ("WOW! I'm on Level 10!"), likes ("I got 28 likes!"), saving their designs to the gallery ("Let's save it! What do you want to call it?"), and buy and selling designs in the shop ("Are you buying things? That's a waste of money!”). Within the design process, students expressed excitement about things they discovered, such as how to position, resize and attach objects (“I know how to make a blocky thing!”). They were also particularly excited about aesthetic dimensions of the design process, especially colour choices (“Choose the colour first! I want red!”). Students were excited by other students’ interpretation of their designs (“Wings? They’re not called wings!”), as well as interpreting other students’ designs (“That looks like a flower boat!”).

Students’ use of the *Makers Empire 3D* app interface also affected their engagement with the design activity. One pair of Kindergarten students were unaware of the need to drag objects from the browser over to the canvas, becoming flustered when they tapped the object in the browser and the object on the canvas automatically changed. Several Year 1 students struggled with intersecting lines as they attempted to draw shapes in the Shaper tool. Students in all year groups appeared to find resizing objects a challenge, for example, when one pair of Kindergarten students flattened a hat object when they were attempting to attach it to the body of their character. Several students were also disappointed when browsing the gallery and unable to find their previously saved designs. Aside from these technical challenges when working with the interface, some students also shared conceptual problems as they worked. One Kindergarten student conceded, “I really don’t know how to make a boat” when working with Blocker. Several of his peers also appeared to struggle with 3D representations of their boats, and the idea that they need to build a frame with a base and walls for the boat to be buoyant. In these cases, students appeared to be emotionally engaged with the activity and concerned about their difficulties using the interface.

In contrast, there were instances of off-task behaviour that suggested that students became distracted by some of the extra features in the application platform beyond the design canvas. Off-task behaviour was often observed with the invitation for further avatar customisation after students received “Level Up” notifications. It was not unusual to observe students spending several minutes customising their avatars because of a “Level Up” notification in lieu of working on their designs. Other students appeared to regularly exit the canvas view and spend substantial portions of the lesson browsing the gallery and discussing unrelated designs they see. Significantly, several students in Year 2 were clearly distracted by the token system, and motivated to generate as many tokens as possible through a negotiated system of liking, buying and selling designs. For example, in Lesson 2.5, students appeared to only briefly work on their design as instructed by the teacher, and quickly became focused on the process of logging out, logging back in as a different user, liking, buying and selling designs, receiving further “Level Up” notifications and generating tokens. Perhaps because the students appeared so engaged, it was difficult for the teacher to identify and remediate the off-task behaviour. These students were clearly proficient in their use of the technology. One possibility for their behaviour is that the students felt they were finished with their design, and that it was acceptable to explore the platform further as a reward for finishing early. Regardless of the underlying reasons for distraction and off-task behaviour, it is important to note that most lessons involved students being highly engaged with the interface and keen to work on their designs.

## 8.10 Theme 5: Interface Interaction

Theme 5 includes a broad range of actions that students took when using the interface, and the enumeration of these points to some important findings in the analysis.

Table 8.8 – Screen Recording Interface Interactions – References and Words Coded

| ***Interface Interaction*** | **No. References** | **No. Words Coded** | **Related Main Actions** |
|---:|---:|---:|---:|
| *Object Creation* | 193 | 1,610 | Adding an object to the canvas, combining components |
| *Deletion* | 69 | 436 | Deleting object components or entire objects |
| *Positioning* | 60 | 584 | Moving objects around the canvas |
| *Aesthetics* | 60 | 416 | Colouring objects and object components |
| *Restart* | 51 | 329 | Starting again after deleting or exiting a design-in-progress |
| *Rotation* | 43 | 231 | Rotating an object or the canvas |
| *Exploration of Platform* | 39 | 833 | Browsing and searching the gallery, customising avatars |
| *Resizing* | 34 | 254 | Resizing a component or object |
| *Level Up Notification* | 26 | 117 | Receiving a Level-Up notification |
| *iPad Keyboard Login* | 15 | 170 | Logging in using the iPad keyboard |
| *Attachment* | 6 | 37 | Attaching objects to other objects |
| *QR Code Login* | 6 | 32 | Logging in with a QR code |

The two most frequently coded actions were object creation and deletion. It was common to see multiple instances of adding, deleting and re-creating objects in a single lesson, and across the data, there were 48 recorded instances of students completely abandoning and restarting designs mid-way into, or even towards the end of, the lesson. With very few exceptions such as Charlotte and Polly – who worked on their 3D house and furniture over the two lessons recorded – students seemed to prefer starting designs from scratch in each lesson, regardless of the stage of lesson recorded. Where teachers' dialogue was captured, they appeared to be supportive of students deleting and restarting their designs. Suggestions to delete and restart designs occurred more than the few instances where teachers could be heard encouraging students not to abandon – but rather fix – an existing design.

Positioning was another frequently recorded action, wherein participants sought to move added objects to form their designs. Generally, students found it easy to move objects around the canvas, and the action of positioning appeared to be a way to form a basic design made up of constituent components, such as a character with feet, or a blob body and glasses to represent eyes. Positioning could also be seemingly random, such as when students appeared to add more objects than they needed and then positioned these randomly as if to explore possible representations. It was interesting to note the relative absence of attaching observed in the videos. Although students readily positioned objects as a key step in forming their 3D designs, very few students took the extra step of attaching objects, though some students communicated their difficulties attaching objects in snippets of dialogue as they worked on their designs.

Similar to positioning, the actions of resizing and rotating objects also frequently featured in the screen recordings. As noted in the analysis of the *Design Thinking* theme, rotation appeared to have a dual function of enabling students to interpret other students' designs in the gallery, as well as allowing students to interpret their own designs as they work. As students explored the platform, rotation often coincided with verbal cues such as "what did that person do?" or "what's this in the shop?". Similarly, it appeared that students working in pairs often shared the iPad, with one student using rotation to explore what their partner had done, and with phrases like "what have you done?" and "that looks like a…" to indicate that interpretation was the focus at that stage. By contrast, resizing usually immediately preceded or followed the positioning of objects, and appeared more in line with ideating an initial design. Unlike rotation, resizing presented some challenges, with common questions like "how do you make it bigger?" indicating that the student was attempting to resize an object. For some students, resizing a shape in two dimensions seemed to present fewer challenges, and when they raised or lowered the height of a three-dimensional object, they appeared to struggle, stating "I can't make it higher", "I can't make it taller" or similar.

Finally, logins and notifications represented ostensibly minor aspects of the interface interaction, but also ones that warranted closer analysis. While there were six instances of students logging in with QR codes, most students logged in using the iPad keyboard. This appeared to present considerable challenges for Kindergarten students, many of whom were paused at the login screen for the first three-to-five minutes of the screen recording. On the other hand, Year 2 students appeared to have very few issues logging in, with four instances of the screen recording occurring after the initial login. Some of these Year 2 students also readily logged out and log back in again during the lesson, mainly to arrange the buying and selling of objects through a single iPad. There were 26 instances of "Level Up" notifications, which occurred at random times based on the user's activity and experience with the system. Students were often audibly pleased with these notifications, exclaiming, for example, "I'm now on Level 10!" to their peers and/or teacher. However, most of these notifications were followed by a view of the avatar, and this proved a distraction for many students, who proceeded to customise their avatars in lieu of doing further work on their designs.

## 8.11 Limitations of the Video Screen Recordings

The challenges of working with screen recordings are many and varied. The videos accurately captured the actions students took when engaging with the application interface. Arguably, however, they did not accurately or objectively capture the breadth and depth of students' learning. Learning outcomes noted elsewhere in the report – such as creativity, problem solving, and critical thinking – could not be reliably identified in these recordings without further triangulation. For example, some recordings showed that students quickly and efficiently designed objects with a minimum of fuss, though it was not clear if the students were simply following a previous design or producing their own original design – thus it was problematic to conclude that the designs evidenced creativity or critical thinking. Elsewhere, students seemed to struggle through the creation, positioning and attachment of objects, and while they were perhaps learning problem-solving skills, the progress they reached was limited. This finding cuts to a problem at the heart of qualitative research – the observable behaviour is not necessarily an accurate proxy for participants' thinking. As well, the snippets of dialogue recorded were exactly that – snippets that the research team was able to identify in noisy and productive classrooms where a multitude of related conversations could be heard in the background. Finally, while students worked in pairs, it was rarely, if ever, possible to ascertain which student was working on the iPad at which time, and which aspect of the design was the product of which student's efforts. In some cases, it was somewhat evident that students were of differing levels of ability, which again made it difficult to draw conclusions about which students were demonstrating which learning outcomes and which students were not.

Finally, the screen recordings that were captured only constituted a portion of the observed students' time on the *Makers Empire 3D* app, so considerable amounts of their learning and associated issues were not captured. Likewise, the recordings only constitute a handful of students amongst the hundreds of students who took part in the study, and it was not possible to determine whether the phenomenon observed were broadly representative of the sample, or of student use of the app more broadly.

## 8.12 Video Screen Recordings: Summary and Concluding Remarks

Despite the limitations noted, the video screen recordings provided substantial insight into how students engaged with the *Makers Empire* interface to design 3D models using a range of tools and features within the application platform. Like their teachers, these students were being exposed to the application – and perhaps to 3D design in general – for the first time. Although the points of progress depicted in screenshots in the recording summaries suggested that some students made limited visible progress in their designs, the logged episodes went some way to showing the knowledge and skills they nonetheless gain.

Coding according to the *Design Thinking* first-order theme revealed some interesting aspects of student behaviour. For many pairs, there was a repetitive cycle of object creation, deletion and re-creation, and this appeared to affect students' progress. At the same time, Stage 3 (Ideation) of the IDEO Design Thinking model encouraged the generation of many potential designs while deferring judgment, building on the work of other peers, visualising and describing ideas as they unfolded, and evaluating the viability of designs at key points in the process. Perhaps more than any other stage, ideation was evident in the way students interacted with the interface and in the snippets of teacher dialogue where students were encouraged to come up with more than one design. It seemed unfortunate, though, that students were keen to delete their work – perhaps prematurely – often without discussion about why the design needed to be restarted. Unnecessary deletion of designs in lieu of critical refinement may well have prevented some students from proceeding from the Ideation stage to the later Experimentation and Evolution stages. Nonetheless, students were very comfortable with ideating and experimenting through object creation, positioning and aesthetic dimensions such as styling and colouring their designs as they go. Challenges and setbacks appeared relatively minor in contrast.

During the analysis, it was rare to observe sustained development of a single design across the early, mid and late stages. The research team hoped to capture designs that students started at the beginning, and that would unfold over the course of, the unit of work. Instead, most lessons appeared to be self-contained, with designs that students mostly start from scratch, and in some cases only work on for ten-to-15 minutes before restarting a similar design from scratch. This may relate to the nature of the tasks being set. For example, in Videos K.1-K.3, students were only required to build objects using Toy Designer, while in Videos 1.4-1.6, students were constructing simple 2D characters. Both activities seem to suggest easy points of entry and early points of completion. By contrast, the activity in Videos 2.1-2.2 required students to design a spinning toy, and the added layer of complexity seemed to challenge students further and engage them for longer periods of time. It was possible that, not having taught with the technology previously and being responsible for teaching younger years, Emma and Ella mostly erred on the side of setting relatively easy lessons, feeling that their students needed to build knowledge and skills before working on more challenging tasks. With lessons averaging seventy minutes in length, Kirsten appeared to strike a balance between explicit modelling and large periods of time where students work on their designs. With this latitude, Charlotte and Polly were able to design a multi-storey house and accompanying items of furniture. However, the same degree of latitude resulted in several students in Videos 2.4 and 2.5

being off-task for most of both lessons, being more focused on generating tokens and customising avatars than on making meaningful progress with their designs.

Despite the challenges, students clearly loved engaging with the technology, and were excited by their progress in both the designs and in other aspects of the application platform such as tokens, likes, levels and avatars. Students seemed to see the app as an experience that went beyond simply designing 3D objects. The captured snippets of teacher dialogue suggested that teachers were keen to trust their students and prompt their thinking at key points to solve challenges they encounter rather than giving them straightforward answers or telling them what to do. Students' dialogue suggested that they enjoyed working with their partners in the design process, and felt comfortable sharing their ideas, problems and questions. To a large extent, the recorded videos show that 3D design applications such as *Makers Empire* could be a powerful vehicle for student-centred and constructionist learning.

# 9 Reflective Journal Analysis

*Themes emerging from teacher reflective journals were inductively coded. Teachers identified a range of strategies that supported learning in makerspaces, including explicit instruction, modelling, open-ended inquiry, pair work and group work, class discussion, questioning, scaffolding, reinforcement and revision. Teachers in turn referred to helpful resources such as models, presentation slides, visual cues, and QR codes. In their journal entries, teachers also documented a range of challenges that they experienced, including finding an appropriate problem, experiencing technical difficulties, having limited access to equipment. Teachers further documented challenges they believed their students faced, observing their misconceptions about what could and could not be 3D printed (such as working robots) the emerging nature of their understanding of some concepts (for instance, of ratios), the propensity of some students towards off-task distraction, and the realisation that the collaborative skills of some students were still emerging. Despite the challenges, all teachers were able to identify positive outcomes from their unit of work, including the development of critical thinking, communication, creativity and problem solving, improvements to learning behaviours such as risk-taking, engagement, enthusiasm and autonomy, and improvements to technical proficiency. Teachers highlighted how engaged and enthusiastic their students were about the technology, the design process, and their finished products.*

## 9.1 Introduction to the Reflective Journal Analysis

This chapter presents the analysis of teachers' written lesson reflections. The lesson reflection activity and questions are first discussed, followed by a brief account of descriptive statistics related to the data. The section then explains the coding structure and hierarchy that emerged during the inductive analysis of content and provides a detailed discussion of themes grouped by five first-order categories: (1) *Lesson Focus;* (2) *Teacher Strategies;* (3) *Challenges Encountered;* (4) *Positive Outcomes;* and (5) *Next Steps*.

The data that have been enumerated for this analysis drew on the 24 teachers who participated in the lesson reflection activity. This number took into consideration the three non-teaching participants involved in the study who did not implement or reflect on units of work. This represented a reduced sample size in comparison to the 27 teachers that participated in the professional learning program. As such, all enumerated findings presented in this section are based on the reduced sample size (that is, n=24, 100%).

## 9.2 About the Journal Reflections

As part of their participation in the *Makerspaces in Primary School Settings* project, all teachers were asked to spend approximately 25 minutes each week documenting thoughts and observations about lessons that incorporated Makerspaces, as close as possible to the time the actual lessons were taught. Teachers were also invited to include relevant artefacts that related to the taught lessons, with lesson plans, resources, units of work, and work samples being offered as possible examples. 12 questions were used to form a guidelines document shared with teachers during the professional learning program, and teachers were free to consider any of these questions when writing their reflections:

1. When did the lesson occur?
2. Where did the lesson occur?
3. What was the overall design of the lesson?
4. How did you feel the lesson went?
5. How did the students respond (e.g. emotionally and behaviourally) to the different sections of the lesson and how do you know?
6. What knowledge and skills did you feel that the students learnt during the lesson?
7. What were the main difficulties that students experienced and why (and how did they deal or not deal with them)?
8. Did you notice any specific misconceptions that students held and were these able to be resolved?
9. Did you try any particular teaching approaches / strategies during your lesson, and if so, how well did they work?
10. Overall, what best supported learning in this lesson and why?
11. Overall, what would help improve learning next time and why?
12. Other (any other thoughts)

In addition to freely referencing any of the questions included in the guidelines document, teachers were advised that their reflections did not need to conform to any specific structure, length or formatting requirements. Google Drive folders were created for each participant and shared privately to their work email address such that reflections could only be privately viewed by the research team and not by other participants. Regular reminders were sent out by email to encourage teachers to write reflections concurrently with the teaching of makerspaces lessons.

In total, 102 lesson reflections were recorded. With an average of 4.25 reflections per participant, the number recorded for each ranged from zero to ten. Approximately one third of the teachers in the cohort (n=7, 29.2%) uploaded artefacts to their reflection folder, with most of these artefacts being photographs of student work samples. Much less common were lesson plans, units of work, resources, and presentations. Table 9.1 provides general descriptive statistics for the reflections recorded.

Table 9.1 – Lesson Reflection Descriptive Statistics

| | |
|---|---|
| *Total Reflections:* | 102 |
| *Average No. Reflections / Teacher:* | 4.25 |
| *Max.* | 10 |
| *Min.* | 0 |
| *No. Teachers with Artefacts:* | 7 |
| *Total No. Artefacts Included / by type:* | 80 |
| *Lesson Plan:* | 2 |
| *Unit of Work:* | 2 |
| *Presentation:* | 3 |
| *Resource:* | 2 |
| *Work Sample:* | 71 |

The reflection data were explored inductively, through segmenting, coding and the creation of category systems in NVivo. Despite the structure implied by the 12 guiding questions used to prompt reflection, the lack of requirements in terms of question selection, formatting, structure and length meant that the resulting raw data were mostly unstructured. Furthermore, there was overlap in terms of ideas explored in each of the questions. For example, while many teachers chose to answer Question 7 ("What were the main difficulties that students experienced…?"), teachers also referenced difficulties when responding to Question 4 ("How do you feel the lesson went?") or when identifying improvements in Question 11 ("…what would help improve learning next time?"). Similarly, there was an overlap evident across Questions 9 and 10, with many teachers referencing strategies as an element that best supported learning in their lesson, and/or the use of resources identified as "supports" constituting a strategy. Ideas conveyed in response to Question 3 ("What was the overall design of the lesson?") were often developed further in subsequent questions, such as referencing the strategies that informed the design of the lesson in Question 9. There was also a blurring of the distinction between the "misconceptions" explored in Question 8 with the "main difficulties" explored in Question7, with some teachers seeing these two areas as rather similar in nature. Finally, some teachers chose to use Question 12 ("any other thoughts") as an opportunity to describe the next steps that would be taken to realise the needed improvements that were identified in Question 11.

Table 9.2 shows the coding structure and hierarchy that emerged through the inductive analysis of the data. Five first-order themes emerged, including: (1) *Lesson Focus*; (2) *Teacher Strategies*; (3) *Challenges Encountered*; (4) *Positive Outcomes;* and (5) *Next Steps.* Column 2 (Number of Coding References) provides an indicator of the frequencies with which data associated with the themes occurred, while Column 3

(Number of Words Coded) provides an indicator of the level of detail provided across the responses. A discussion of the themes is provided in the section that follows.

Table 9.2 – Coding Structure Employed in QSR NVivo (Version 11)

| ***Code*** | **No. Coding References** | **No. Words Coded** |
|---:|---:|---:|
| *Lesson Focus* | 216 | 6,146 |
| *Lesson Focus\Offline* | 53 | 1,695 |
| *Lesson Focus\Online* | 57 | 1,507 |
| *Teacher Strategies* | 335 | 11,794 |
| *Teacher Strategies\Class Discussion* | 15 | 573 |
| *Teacher Strategies\Explicit Instruction* | 58 | 2,595 |
| *Teacher Strategies\Modelling* | 19 | 844 |
| *Teacher Strategies\Open-ended Instruction* | 33 | 1,126 |
| *Teacher Strategies\Pair Work & Group Work (incl. peer instruction)* | 14 | 437 |
| *Teacher Strategies\Questioning* | 6 | 213 |
| *Teacher Strategies\Re-enforcement and Revision* | 6 | 226 |
| *Teacher Strategies\Scaffolding* | 8 | 238 |
| *Teacher Strategies\Use of resources and other supports* | 61 | 1,750 |
| *Challenges Encountered* | 263 | 8,519 |
| *Challenges Encountered\Conceptual Challenges* | 35 | 1,027 |
| *Challenges Encountered\Misconceptions* | 31 | 1,276 |
| *Challenges Encountered\Problem Learning Behaviours* | 30 | 824 |
| *Challenges Encountered\Teacher Confidence with Technology* | 4 | 85 |
| *Challenges Encountered\Technical Difficulties* | 52 | 1,666 |
| *Positive Outcomes* | 358 | 10,537 |
| *Positive Outcomes\Autonomy* | 2 | 40 |
| *Positive Outcomes\Collaboration* | 39 | 1,167 |
| *Positive Outcomes\Communication* | 8 | 226 |
| *Positive Outcomes\Creativity* | 8 | 306 |
| *Positive Outcomes\Critical Thinking* | 8 | 381 |
| *Positive Outcomes\Engagement* | 51 | 1,237 |
| *Positive Outcomes\Enthusiasm* | 70 | 1,326 |
| *Positive Outcomes\Problem-Solving* | 8 | 296 |
| *Positive Outcomes\Risk-taking* | 6 | 308 |
| *Positive Outcomes\Technical Proficiency* | 26 | 1,002 |
| *Next Steps* | 91 | 2,533 |
| *Next Steps\3D Printing* | 1 | 17 |
| *Next Steps\Allowing More Time* | 19 | 284 |
| *Next Steps\Design* | 11 | 218 |
| *Next Steps\Feedback and Discussion* | 9 | 326 |
| *Next Steps\Inquiry* | 5 | 157 |
| *Next Steps\Overcoming Technical Issues* | 7 | 117 |
| *Next Steps\Re-organising the Learning Environment* | 13 | 485 |
| *Next Steps\Revision* | 8 | 382 |
| *Next Steps\Task-Unit Modification* | 6 | 131 |
| *Next Steps\Testing* | 1 | 19 |
| *Next Steps\Trying New Strategies* | 15 | 439 |

## 9.3 Theme 1: Teachers' Reflections on *Lesson Focus*

When coding *Lesson Focus*, the research team looked closely at Question 3 ("What was the overall design of the lesson?"), but also examined information shared about the lesson in other questions, such as Question 6 ("What knowledge and skills…?"), Question 9 ("Did you try any particular teaching approaches/strategies…?") and Question 10 ("…what best supported learning…?"). The lessons broadly fell into two main categories: first, the "offline" lessons, where students engaged in maker activities that mainly incorporate physical materials; and, second, "online" lessons, where students mainly used the *Makers Empire 3D* app. Consistent with the lesson observation findings, some lessons involved both offline and online maker tasks – for example, in the form of learning stations and group work.

Most teachers (n=19, 79.2%) referenced "offline" activities in their reflections. The focus of these lessons included prototyping, planning and testing activities. In several reflections on early-stage lessons – such as those of Alice, Hannah and Nadia – planning was articulated as a process that involved responding to a problem and utilising inquiry, group interaction, discussion and ideation to plan possible solutions. Underscoring the need to first engage learners in the planning process, Alice referred to her opening lesson as "the hook lesson… dramatizing the problem and hooking them in to trying to find the solution". Hannah described a lesson during which students planned possible keyring designs to reflect the needs and interests of teachers, where students were "placed in small groups to brainstorm questions for particular teachers… and [then] asked teachers their questions… and designed their own keyring for the individual teacher using responses obtained". Nadia summarised a lesson that began with "whole class discussion of what makes a good hook [where] we brainstormed students' ideas… then [is] followed by the students sketching their personalised hat hook and then physically making their design out of recycled materials". Prototyping generally occurred in the mid-stage lessons and involved the use of wide range of physical materials to create an object that was often similar in form or function to the 3D objects that were designed. For example, Amanda's Kindergarten students used both natural and synthetic materials to "build a boat that would float and hold a teddy", whereas Kirsten's students made clay prototypes of their playground sculpture models "to understand what shapes are needed when we use the *Makers Empire 3D* app". By contrast, testing usually followed the successful printing of 3D objects. Both Ella and Emma utilised testing to ensure that the students' printed designs were fit for purpose. Ella's Kindergarten students went to the outdoor makerspace to test whether 3D-printed boats float, whereas Emma's Year 1 students used a shadowbox and light to see if their 3D-printed characters cast sufficient light.

A similar majority of teachers (n=22, 91.7%) referenced "online" activities in their reflections. For several teachers (n=7, 25.9%), the focus of the early-stage lesson reflections was a whole-class introduction to the *Makers Empire 3D* app. The success of these lessons appeared tied to the strategies employed – mainly the balanced use of explicit instruction, modelling, and some time to experiment. For example, Nadia described a successful lesson where "students worked in pairs to log onto the *Makers Empire 3D* app and follow explicit step by step instructions to complete the first challenge in the shaper design section of the app", while Amanda incorporated both modelling and play in her introduction:

> In today's lesson, I introduced the Makers Empire 3D app and encouraged the class to have a play around on it and practise logging on correctly and saving their work. I demonstrated how to log on and create a simple character for about ten minutes, and then I gave the students the rest of the lesson to have a try.

In the mid-stage reflections, teachers such as Emma, Hannah and Kirsten encouraged experimentation, play and further discovery. Having explored the problem of designing 3D characters, Emma's students spent time "experimenting with the draw tool in the shaper application… to replicate shapes and flip them to create a human character", and Hannah's students similarly "investigated the Shapers section [tool] in *Makers Empire* to draw a variety of ideas for a safety bag tag". In a mid-stage reflection, Kirsten stipulated a learning goal of "exploring the features of Toy Designer to make a better spinning toy than the one I made". Late-stage lessons appeared to incorporate consolidation and revision to ensure that students connect the design process with related knowledge and skills. For example, Julia described a lesson where students focused "on knowing names of 3D shapes (haven't covered that since Term 2) and what could be the best shape to suit their purpose". Towards the end of her unit of work, Penny had a lesson focusing on "a review of tools used so far, rules for saving, design criteria, and peer review tips". Late-stage lessons also emphasised reaching the finished product, for teachers such as Mackenzie, who stated "the intention for this lesson was to have all groups finish their designs and have them ready for printing over the next few days", or Kim, whose students successfully printed "objects [characters] to use in our movie and make the settings for our movie".

## 9.4 Theme 2: Teachers' Reflections on *Teacher Strategies*

When coding *Teacher Strategies*, the research team looked closely at Question 9 ("Did you try any particular teaching approaches/strategies…?"). However, strategies were often referenced in the design of the lesson that was described in response to Question 3 ("What was the overall design of the lesson?"). Moreover, the code *use of resources and other supports* was in part created to reflect the ways that teachers made use of many of the supporting resources identified in Question 10 ("…what best supported learning…?").

In total, 22 teachers (91.7%) referenced teacher strategies in their reflections. These strategies fell into nine categories, which are shown in Table 9.3. Of note, explicit instruction, open-ended instruction and use of resources and other supports were referenced by most teachers, and the number of coding references for explicit instruction and use of resources suggested that these strategies were the most commonly-used. Far less commonly-referenced were the strategies of questioning, re-enforcement and revision, and scaffolding. These strategies appeared to be used only occasionally and by a minority of teachers. Class discussion, modelling and pair/group work featured in approximately one third of cases where they were, on average, referenced more than once.

For the teachers referencing explicit instruction in their reflections (n=19, 79.2%), the lesson focus was often very detailed and specific, sometimes utilising imperatives such as "had to" and "have to". For example, Sophie described a structured lesson where students had "to design a star badge with their name, changing colour, size and shape (20 minutes) with the teacher circulating to assist [students working in] pairs", and another lesson where students "have to create an ice cream cone with four different colours and sized scoops on top". She felt her students "grasp skills better when focused on a set task". For Ella, Hannah, Penny and Emma, explicit instruction was useful for introducing concepts and ensuring that the class understands the task ahead of them. Ella employed explicit instruction when guiding her students through the introduction of important concepts such as "floating" and "sinking". She then allowed them some time to play with the Blocker tool, but followed this with further explicit instruction, reflecting that "exploring this new part of the app was a lot smoother than introducing Shaper… because they'd understood this was a 'low risk' introduction and they knew that more detailed instructions were coming".

Table 9.3 – Range of Teacher Strategies Referenced in Reflections

| ***Teacher Strategy*** | **No. Teachers (n)** | **No. Teachers (%)** | **No. Coding References** |
|---:|---:|---:|---:|
| *Class Discussion* | 7 | 29.2% | 15 |
| *Explicit Instruction* | 19 | 79.2% | 58 |
| *Modelling* | 9 | 37.5% | 19 |
| *Open-ended Instruction* | 15 | 62.5% | 33 |
| *Pair Work and Group Work (incl. peer instruction)* | 8 | 33.3% | 14 |
| *Questioning* | 4 | 16.7% | 6 |
| *Re-enforcement and Revision* | 3 | 12.5% | 6 |
| *Scaffolding* | 5 | 20.8% | 8 |
| *Use of resources and other supports* | 15 | 62.5% | 61 |

Hannah similarly employed explicit instruction in her introduction to creating customised keyrings, noting that “the explanation of the task needed to be explicit”. For Penny, explicit instruction was essential for linking concepts from previous lessons with those explored in the lesson at hand. Referring to her lesson on shadow puppets, Emma reflected that “students need much more guided work for their project... we need to explicitly talk about shadow puppets and students need more exposure to how they work”. For others, explicit instruction was tied closely to modelling, a strategy referred to by nine teachers (37.5%). For example, Nadia described learner autonomy as a benefit of employing both strategies together in her introduction to maker stations: “explicit instruction helps to establish a clear focus, and really directs students towards an evaluation/feedback phase… [whereas] modelling this process helps them develop and apply these skills on their own”. Jenna described her approach as “model-then-do”, where the teacher “explicitly models, then students have a go”. Finally, explicit instruction appeared to be seen by some teachers – and indeed by students – as a necessary precursor to more open-ended exploration. For example, Rachel reflected that students in her class required “some guidance and encouragement to explore different options and be creative”, and that “their ideas were initially limited”. Sally remarked that some of her students “wanted to be shown exactly what to do rather than experiment”.

Open-ended instruction was referenced by 15 teachers (62.5%). Key words readily associated with this form of instruction included “hands on”, “play”, “explore”, “experiment”, “have a go” and “see what they can do”. All these words tended to describe parts of lessons – and in some cases, whole lessons – where students were given choice about what to learn and, to some degree, how to learn. For most teachers in this category, open-ended instruction was applied to the *Makers Empire 3D* app – either in relation to learning how to use the app, or to designing objects with the app. Ella used open-ended play to encourage her students to learn about features of the app and share their findings with peers. Actively avoiding explicit modelling, she reflected that “I didn’t want to show them specific things, as I want them to take risks and be creative with the app”. Kirsten also de-emphasised the role of the teacher as the “shower”, encouraging her students “to use a resource or ask a friend to figure it out themselves… rather than showing them [myself]”. Alice described the benefits of “hands on activity”, observing that her students “are really enjoying using the app, and are quickly learning the functionality of it… [saying] ‘I will just try this’ [and] ‘maybe we should try… don’t worry, we can just undo and try something else…’”. Dawn believed that open-ended play improved both learner engagement and the learning environment by freeing her up to work alongside her students:

> I was able to observe which student combinations were good and not good. The simple ability of allowing students time to play was beneficial as this gave them the confidence/engagement to use it next time around. The classroom environment was good. Some students went under tables, some went in to the computer annex, some students used bean bags, whilst some other students sat on the floor or in chairs.

For Jasmine, open-ended instruction appeared to foster creativity and lateral thinking. Giving her students "free time to experiment and design whatever they want", she observed that "we ended up creating over one hundred and eighty designs, and they [the students] absolutely loved it!". Sally reflected on the successful introduction of the app to her class, noting that she planned "to give more free play with the app in future lessons".

For most teachers referencing the use of resources and other support (n=15, 62.5%), both tangible and intangible resources and supports were identified. For example, both Emma and Alice utilised pre-made, authentic objects to learn about the design process, with Emma "showing a real example of shadow puppet theatre and allowing students to experiment with the puppets" and Alice presenting "a bucket of keys" and giving her students the impossible task of "determining which teacher they belonged to". Both Ella and Kirsten employed PowerPoint presentations to provide students with, in Ella's words, "some key tools that had not been discussed yet" and, in Kirsten's words "the whole lesson [for students] to refer to independently". Nadia employed photographs to visualise problems that the students address, noting that in this lesson, "verbal and visual prompting was key… [and] the class photographs of the problems made them really consider why this was an issue in our classroom". Hannah similarly recognised value in the use of "visual aids" and a "class journal" that documented students' learning. Several teachers – including Amber, Amanda, Jasmine, Jenna, Penny, Sally and Tim – recognised the benefit of having QR codes to assist with the login process. For other teachers, intangible resources included both personnel and the provision of further time. Mackenzie encountered difficulty connecting her iPads to the internet, drawing on the expertise of the research team observer to get "through the firewall on the department site that seems to have been the cause of our earlier technology failures". Alice, Sally, Hannah and Kirsten saw "extra time" as a key support. Referring to a lesson where the "sharing of feedback was cut short due to time constraints", Alice stated she otherwise "would have continued after recess to keep the enthusiasm going". In relation to one of her lessons, Hannah believed that "students required extra time to complete their task effectively", while Kirsten conceded that while her "PowerPoint instructions and sharing with a buddy help… they [the students] may need to have more 'play' time using the app".

Class discussion and questioning were both used to explore the making process, identify gaps in knowledge and skills, ideate possible design ideas, facilitate the giving and receiving of feedback, introduce concepts and share findings. Class discussion appeared in the reflections of seven teachers (29.2%), where it was often cited as evidence of students' improved metacognition and engagement. For example, in Ella's class discussion that followed open-ended design, she observed that "the students were very reflective about their learning designs and were able to identify what worked, what didn't, and what they would have to do to make it work". Referring to her boat design lesson, Amanda noted that "the students loved the challenge [of building a boat that floats], and today we discussed what we found easy or hard about it, and what worked / didn't work in those designs". For the four teachers that referenced the use of questioning (16.7%), the strategy seemed to form the basis of dialogic discourse, a communicative approach to teacher-learner partnerships. Alice used "the think aloud" strategy, which involved "verbalising the problem and wondering why". She believes this strategy was effective for "asking students… to share their ideas… [thus] building up the background knowledge required and setting them up for success". Amanda described more of an ongoing dialogue with her students during the design process, where she supported students "as they designed, asking them what they are doing and helping them to talk through what they could do to fix any problems they have". Dawn simply employed questioning as an important way to probe students' prior learning, while Hannah encouraged her students to develop questions in groups as part of an inquiry process.

Referred to variously by small pockets of teachers, re-enforcement and revision (n=3, 12.5%) and scaffolding (n=5, 20.8%) were nonetheless perceived as effective strategies by the teachers citing them. For Alice, Amanda and Hannah, re-enforcement and revision were used to ensure that students have the necessary knowledge and skills to further their learning. For example, Alice revised "how a question is written" so that students could develop appropriate inquiry questions for their research. Amanda described in detail how she revised important *Makers Empire* instructions for her Kindergarten students, while Hannah believed that it was important to "always come back to our purpose, challenge, and the step we are on". Likewise, scaffolding appeared to help students stay on task and structure their thinking. Amanda and Ella both used a "sink/float" table with images to test students' thinking about the buoyancy of different objects and to generate criteria. Ella reflected on the success of this lesson:

> We made a criteria [sic] as a class for what a successful boat would do. We decided it should float, should stay floating for at least 10 seconds, should hold a teddy bear counter (due to time restrictions we had to print multiple boats at once, meaning that they had to be made smaller, and their characters would not fit, we decided to use teddy bear counters instead), [and] should hold a teddy bear counter for 10 seconds.

Emma used a story with accompanying storyboard scaffold to structure the process of creating 3D characters, while Hannah used a design scaffold with detailed steps for students to follow when designing a safety bag tag.

Finally, one third of teachers (n=8, 33.3%) referenced students working in pairs and/or groups. For Amber, Dawn and Ella, the main purpose appeared to be peer instruction. Amber's strategy was to "ask more confident students to assist and demonstrate what they know to other students who are struggling", while Dawn employed "selective pairings of students that are working together inclusively". Ella utilised iPad swapping to achieve peer instruction, whereby "halfway through our app time, the students swap [iPads] so that their partner can work on their design", observing that this strategy "really improves what they make, [and] most designs were are lot clearer and more logically put together". Hannah used grouping by allocating topics to pairs of students who then research these topics together. Amanda felt that introducing features of the *Makers Empire 3D* app in a previous lesson "was a bit much for the class, and it was hard to keep track of whether all students understood what was going on". She decided instead to "work with small groups to introduce Blocker". Similarly, Julia felt that "a small group works much better than the whole class… students feel a sense of support with the teacher working alongside them to overcome problems and direct and solve their own difficulties".

## 9.5 Theme 3: Teachers' Reflections on *Challenges Encountered*

The first-order *Challenges Encountered* code directly relates to Question 7 ("What were the main difficulties that students experienced and why, and how did they deal or not deal with them?"). Almost all teachers in the teaching sample (n=23, 95.8%) referenced at least one challenge, and the overall 263 references and 8519 words coded across the dataset indicated that this area received much attention in many of the reflections examined. While the challenges teachers encountered might be viewed in a negative frame, it is important to note that this theme also referenced many of the strategies employed to overcome the challenges, and that in their reflections, most teachers appeared relatively unfazed by the challenges they did encounter.

Among the most commonly-referenced challenges, technical difficulties were cited by 18 teachers (75%). The clear majority of these challenges pertained to problems with 3D printers, connectivity issues, and difficulties using the *Makers Empire 3D* app. Most teachers simply listed the challenges encountered without elaborating on the impact of this challenge on learning in their classroom, though there were some exceptions to this. For example, Ella described in detail, the problems with her 3D printer, and the impact – both positive and negative – on her Kindergarten students:

> We had a few issues with printing, where the rafts would not stick to the board, and so the printing would move and become a big mess, however this taught the class resilience and persistence, as we changed some things and tried again. Eventually, I swapped the filament to PLA and changed to the perf board and this combination was successful. One thing that was harder than expected was removing the rafts and extra filament from the printed models, this is something I had to do for each design as the students were unable to do this themselves and it took a lot longer than expected. As we printed, a few designs had pieces that were not joined, and this really helped the class to understand that they have to view their designs from all angles to make sure there were one piece (something I had tried to explain, but seeing it happen helped them to understand). After this lesson, I have seen major growth in their ability to use the app, problem solve on their own, or with the help of a friend, to be persistent and to work harder to create one beautiful thing, rather than multiple ok designs.

Jasmine likewise criticized the unpredictability of her 3D printer, noting in one lesson that “the 3D printers were not working… at first the printer said the platform was too hot and it wouldn’t work”, and further noting that “a few days later, I tried again and it successfully started… however, halfway through the job, the platform again became too hot and it stopped working”. Being able to successfully print in her class, Kim nonetheless drew attention to “the difficulty of having to be patient and wait for the creation to print, as it takes a long time”.

For nine teachers (37.5%), connectivity issues prevented one or more iPads in their class set from logging in. Mackenzie conceded that “unfortunately, technology let us down again… most groups were unable to work on the app due to connection problems, or [the] very slow loading of the app” and stressed that “connectivity/broadband issues are definitely having an impact”. Madalyn painted a similar picture when, in one of her lessons, “as far as we could see, the Wi-Fi was connected but the app wouldn’t open”, adding that “this caused some chaos, as students were very impatient waiting for staff to try and fix the problem”. Alice simply noted that “some of the iPads would not log into the Makers Empire app… [and] we really need 1:1 iPads in the classroom”.

For 14 teachers (58.3%), technical difficulties were evident in students’ use of the app. For example, Amber, Alice, Emma and Dawn noted the difficulties encountered when students were attempting to create, resize, rotate and join objects. For Kim, Nadia and Madalyn, the app presented literacy and numeracy challenges that were particularly evident for younger learners. Kim observed that “a lot of the children have difficulties in operating the program and understanding mathematical reasoning - for example, the ratios and dimensions”, whereas Nadia pointed out the challenge of her Kindergarten students being unable to read the feedback provided in the app. Madalyn believed that the app "is quite difficult for students to navigate… [given that] Kindy and Year 1 students are not very dexterous".

Almost half of the teachers (n=11, 45.8%) referenced student misconceptions as a challenge they encountered when teaching in makerspaces. For Diana, Ella, Rachel, and Sally, the main misconceptions lay in students' beliefs about what could and could not be successfully 3D-printed. As Ella elaborated, "the main misconception prior to starting was the HUGE [her emphasis] plans that the students had – for example, making toys with moving parts, robotics, etc.". To overcome this challenge, Ella printed "a model the day before to give them an idea of the toy we'll be making". Similarly, Diana described the impractical nature of many of the designs of her Year 1 students ideated – including giant robots with mechanical arms – in response to the problem of tangled headphone cables. Employing a critical class discussion, she introduced a scaffold with three key questions: (1) "What will work?"; (2) "What won't work?"; and (3) "What is ACHIEVABLE? [her emphasis]". Rachel noted that in her classroom, "many students did not realise that parts of their drawn plan would be extremely difficult to replicate… they only found this when using the playdough and experimenting with the app", while Sally succinctly identified the misconception as students believing "that anything they put on the baseboard will print as they want it". For Alice and Nadia, the misconceptions lay in students being unable to recognize the problem being introduced. Alice reflected that she "was initially surprised that students could not really see a problem at all… upon being presented with a bucket of keys, they felt they could just walk from room to room to see who owned the keys!". Nadia related that "at first, students struggled to see what our potential classroom project was", further elaborating that "because of the non-English speaking backgrounds of most of the students in my class, the concept of having a bag hook and a hat seemed to confuse them".

For the other teachers in this category, misconceptions were most commonly related to the *Makers Empire 3D app*. Amanda's students did not realise that "using the smallest blocks would lead to more holes and mistakes [in their boat designs]", while Dawn's students thought "their product is connected as one object, but because they cannot rotate or make it taller, their object is not connected". Julia and Kim had students that did not realise how scale and size operated from the app to the final, 3D-printed product. Julia's students wanted "to resize an object on the platform by pinching their fingers on the screen… not tapping to access the tools button", while Kim's students all accidentally printed very small objects, prompting her to reflect that "the concepts of ratio and dimensions are quite difficult for infant children to grasp". Tim's students did not correctly distinguish between taking photos on the iPad and scanning QR codes.

Closely-related to the misconceptions were the learning challenges that ten participants (41.7%) reference in their reflections. For Alice and Hannah, students struggled with forming and asking questions, especially, in Alice's words, "thinking beyond obvious questions such as 'what's your favourite colour?'". Emma's students were "unclear on what to design" when thinking about characters to suit a narrative. Kirsten's students really struggled with replicating clay designs in the *Makers Empire 3D app*, noting that while "the clay sculptures help the students adjust their designs, finding the appropriate shapes is still difficult for most students". Molly's students similarly struggled to identify the shapes that best suit the replication of their offline keyring designs, while Sally's students were "eager to start, but not sure how to problem solve the specific task – to make a book box tag". For Penny, Nadia and Julia, written instructions in the app were especially challenging for their students. As Nadia related, "because the students can't read the instructions or the tab feature, a lot of problems are being solved by random pressing of buttons or reliance on the teacher". Mackenzie pointed out that written success criteria "is difficult for most Kindergarten children… [who] feel that the criteria focused on the unit rather than the design process".

Behavioural issues represented a challenge also noted by ten participants (41.7%) in the sample. Issues included distraction, occasional disengagement, problems working with peers, and reliance on the teacher. For Abigail, Tim and Emma, disengagement appeared linked to iPad use, with students becoming disengaged as they wait for their turn on the iPad. Jenna's lessons also involved pairs sharing iPads but working together at the same time; for her, students "couldn't agree on the image they want to choose for their boat". Madalyn's Kindergarten students "struggled with collaboration… with each student wanting to draw/design in their way, and groups struggling to talk and reach a consensus". Mackenzie said her students "prefer to work individually rather than sharing their ideas", while Tim's students struggled "to share and take turns on the iPads". Alice's students "found it really hard to ask their peers for help… [and] come straight to the teacher so they can be 'told' a solution". Kim's students became side-tracked, "spending so much time making their objects 'pretty' that they forget it prints in one colour", while Penny's students were asked to design a submarine "but some still wanted to play with other sections". Sally observed that, in her classroom, "a lot of students want to be told what to do or how to solve the problem".

Finally, a small number of teachers (n=4, 16.7%) referenced their confidence with technology as a challenge encountered. In her opening reflection, Amber conceded that she felt "a bit unsure presenting this [*Makers Empire*] app, as I feel I don't know how to confidently navigate it". Jenna likewise wrote in her first reflection that she wasn't "too confident with some things such as saving it [the design], as I only ever sent it to email and the student iPad had no email". In her opening reflection, Sally simply observed that, throughout the process, "I am learning too". Penny was unusual in referencing confidence in the reflection for her fifth lesson, where she was concerned that she didn't "have the skills, and the students haven't worked out how to move the whole design correctly". It was important to note that the relatively very small number of references to teacher confidence stood in contrast to earlier references in the pre-professional learning questionnaire that teachers completed prior to commencing their professional learning. Furthermore, Amber, Jenna and Penny all seemed to resolve their confidence issues by later lessons, making Penny a unique case in terms of questioning her skills at a later stage in the teaching and learning implementation.

## 9.6 Theme 4: Teachers' Reflections on *Positive Outcomes*

*Positive Outcomes* were identified by examining responses to all the questions included in the reflection guidelines. From the first-order theme, ten second-order themes were identified, as shown in Table 9.4. Of note, the three most commonly-referenced outcomes were enthusiasm, engagement and collaboration, all of which occur in most reflections. The "coding references" column indicates that both engagement and enthusiasm were referred to more than once by most teachers. Technical proficiency is also identified by a substantial portion of teachers. Less common are references to problem solving, creativity, risk-taking, communication and autonomy.

With almost all teachers (n=22, 91.7%) referencing enthusiasm, there appeared a range of reasons underpinning students' enthusiasm for learning in the makerspaces lessons. Many reflections indicated that students were excited when starting to use the *Makers Empire 3D* app for the first time, and when having designed or printed an object successfully. Effective peer dialogue, group work and class discussions were often cited as evidence of students' enthusiasm. For example, Amanda identified the enthusiasm of her students when she observes that "students are saying to each other, 'guys – look what I've made!' and 'hey – how did you do that?'", while in Alice's class, "students are very keen to share their prior learning with the app, and to help each other with the functionality". Julia's students were "excited to share with each other and myself as they go", and Molly's students were enjoying the app so much that they "are now taking risks and sharing their achievements with others". Nadia's students were "excited to explore the features of the app", Penny's "iPad partners are often excitable, with squeals of delight as they work something out, or find out something new".

Table 9.4 – Range of Positive Outcomes Referenced in Reflections

| ***Teacher Strategy*** | **No. Teachers (n)** | **No. Teachers (%)** | **No. Coding References** |
|---|---|---|---|
| *Autonomy* | 2 | 8.3% | 2 |
| *Collaboration* | 15 | 62.5% | 39 |
| *Communication* | 4 | 16.7% | 8 |
| *Creativity* | 5 | 20.8% | 8 |
| *Critical Thinking* | 5 | 20.8% | 8 |
| *Engagement* | 18 | 75.0% | 51 |
| *Enthusiasm* | 22 | 91.7% | 70 |
| *Problem-Solving* | 5 | 20.8% | 8 |
| *Risk-taking* | 4 | 16.7% | 6 |
| *Technical Proficiency* | 9 | 37.5% | 26 |

For Amber, Hannah, Jasmine and Kirsten, the design process seemed to be a strong source enthusiasm for the students. Amber's students loved "creating their avatars", and Hannah's students were "so excited, they keep wanting to create their [keyring] designs throughout the whole lesson". Jasmine's Kindergarten students loved using the app to ideate designs, whereas Kirsten's students "loved working with the clay… and it encourages collaborative discussions about their designs with peers". Rachel's students were "so excited to be thinking, designing, planning together, and sharing ideas". For Madalyn, Mackenzie and Tim, the arrival of hermit crabs was an event that, in Mackenzie's words, "was motivating!". Elsewhere, teachers noted how enthusiastic students were when 3D-printing their designs. For example, Ella remarked that her students were "so excited to watch their designs print", and Kim observed that her students "loved starting to see some of their creations being printed out". Tim's students were especially "motivated to finish their 3D designs after seeing the [model] 3D objects".

Engagement was a concept that was clearly referenced by 18 teachers (75%) in their reflections. The reasons for students' engagement was varied, often related to the specific topic being explored. For example, Alice believed her students were engaged by the introductory lesson she delivered – that students had "really been hooked into the project by the 'drama' of presenting the problem and [providing] hands-on learning". Hannah also felt that her introductory lesson was engaging, stating that her students "always enjoy being introduced to new experiences… [and that] attention was maintained throughout the lesson". For Kim's students, the use of a stop-motion animation provided motivation to stay engaged as they tried "really hard to create their part of the movie". For Julia, Emma, Dawn and Tim, engagement appeared to be linked to the decisions made about the learning environment. Julia utilised pair work, observing that her students were "very quiet… really focused and [show] much concentration". Emma believed she achieved greater engagement by "having a directed [explicit] activity… and giving students a shorter amount of time to complete their activity", whereas Dawn's students appeared to be more engaged because she allowed them to sit wherever they like. Tim was initially concerned about working in a team-teaching environment with three combined classrooms, but nonetheless realised “that most of the students are on-task and engage really well”. Finally, several teachers regarded iPad use as a reason for students being engaged. For example, Ella argued that “children having 1:1 iPads helped them stay engaged during this lesson”, while Jenna’s students were “highly engaged when it comes to iPad use”. Alice’s students became more engaged as their confidence with the app grew, to the point where she regarded them as “the lead teachers”. Jenna’s students “really enjoyed the app… and were engaged the whole time”, and Penny noted that every time she “brings up the [app] screen, they sit ready, waiting eagerly”.

Fifteen teachers (62.5%) referenced collaboration as a positive outcome. Alice described a cooperative classroom culture with “high levels of collaboration and risk-taking… where students are challenged to seek answers from their peers”. Amanda also had a classroom where “there is a lot of helping each other out”, while Ella’s students gradually became “more confident in sharing, asking or solving problems for their peers”. Dawn’s students were “very excited working in pairs” and did so effectively because they had “worked in pairs all year before using the iPads, so there have been no issues with sharing”. Emma’s students were similarly “highly motivated… and collaborate well in [groups with] partners”. Diana listed “confidence… communication… [and] teamwork” as the main positive outcomes for her group work ideation activity, while Julia believed that, for her students, “working with a partner gives them the opportunity to problem-solve together”. In Molly’s classroom, “everyone was interested and engaged in helping each other”, while Penny’s students were particularly good at “asking other students for help” and “taking turns”.

For Madalyn, Hannah and Mackenzie, collaboration was identified as both challenging and rewarding. Although Madalyn’s students “struggled with collaboration a lot”, of the team-teaching environment she reflected that was “great to have our students mixing with others from different classes who they wouldn’t normally work with”. Hannah observed her students working well together but recognised that the “practicality of the task [she set] is complex…. [because] students have to visualise, draw and create as a joint process together – as a class – and independently”. Mackenzie had some concerns about the open-plan, team-teaching environment in which her students worked, but noted that “it was encouraging for me to see some of the students attempting to lead their activity and encouraging the other students in their group to talk about their ideas – learning together!”. Rachel and Penny were generally happy with students’ collaboration, but Rachel conceded that “low-performing students do not appear to contribute their ideas as readily”, while Penny had some “problem” students who did not share iPad use effectively. Sophie stated that “a surprising outcome [for the lesson] is that groups consist of unusual student pairings, which proves to be highly successful for collaboration”. Tim’s reflection drew connections between collaboration, enthusiasm and effective listening skills, prompting him to identify an explicit teaching focus in future:

> Today’s lesson required students to collaborate and work together to put down their ideas. Students were very enthusiastic and excited to prepare the tank before the hermit crabs’ arrival. I saw a lot of students struggling to listen to each other’s ideas. It would be ideal to explicitly teach them how to share their ideas.

Referenced by nine teachers (37.5%), technical proficiency was clearly discussed with the *Makers Empire 3D* app in mind. For Amber, Amanda, Julia, Jenna and Kim, successfully logging in and navigating the app was considered a positive outcome. For example, Amber’s students experimented with an avatar design activity, after which her students felt "confident in using the character [feature], and have a good laugh at the things they can do", whereas Julia's students "explored different content and complete a challenge/tutorial with Shaper". Dawn was particularly impressed by her students "learning how to make new shapes by compositing two solids", while Ella's students "learn about the different buttons in Blocker… and teach each other how to use different controls". Emma's students quickly gained proficiency "in the initial tools I taught [Shaper], which meant they were able to confidently use new tools". Jasmine's students successfully "used Blocker to create a base for their boat".

While not involving many references in the reflections, creativity was referred to by five teachers (20.8%), and communication is referred to by four teachers (16.7%). Amber and Hannah described creativity as more of a basic competency, with students in Amber's class "successfully creating a character", and students in Hannah's class "able to visualise, create and draw their safety bag tags". For Jasmine, creativity was reflected in the students' ability to rapidly ideate, with 180 designs as the product of a single lesson. Both Emma and Alice emphasised creativity as embodied in interesting products and approaches. For Emma, students came up with "some really interesting designs", while Alice's students "adopted the role of detective" as a solution to the posed problem. Likewise, communication was referred to as an elementary skill for Alice, who cited the achievement of English outcomes – especially "how to compose and record a response" and "how to give and receive feedback" – in her makerspaces lessons. Diana listed communication as one of the positive outcomes from her ideation lesson, while Hannah referred to it as an important skill for class discussions and group work. Penny referred to one student in her class, observing that after one makerspaces lesson, "he was more articulate than usual… he normally does not participate in discussions, but was more able to express his ideas clearly using correct terminology".

Critical thinking and problem solving both had references from five teachers (20.8%) in their reflections. In terms of critical thinking, Alice described, in detail, a task where students demonstrated "high levels of refinement of designs" and the "presentation of critical feedback in a positive manner… promoting the development of reflective students". Similarly, many of Amanda's students "scrapped their original designs… based on results when testing and [on observations of] designs that they saw their peers make that had worked better". Having participated in several class discussions where she modelled critical thinking, Ella believed that her students "were very reflective about their designs, and able to identify what works, what doesn't, and what they would have to do to make it work". Hannah recognised that her students exercised critical thinking by "identifying the challenge verbally, written and orally", whereas Jenna's students developed it through "spatial thinking… [exploring] what a boat needs to float and how to design it using a digital format and restrictions – for example, only blocks, [which] can't make a curved surface". In terms of problem solving, Alice's students in one class "were quick to identify a problem and determined to find a solution". Amanda's students were particularly effective in small groups, where she could "answer questions or support students as they solve problems". Ella believed that her students had developed problem solving skills through "persistent, hard fun", while Hannah believed her students could problem-solve through "research and collaboration". Julia emphasised the value of trial and error, describing one student who "tried to use a 3D object but soon realises it may not work, so he changes the object to a flat one".

## 9.7 Theme 5: Teachers' Reflections on *Next Steps*

The final theme was explored by closely examining the end of each reflection, in which many teachers indicated the next steps they saw occurring in teaching and learning with makerspaces in their classrooms.

Next steps often involved having more of something (like time, class discussion, or feedback), trying new things (such as new teaching strategies, reorganising the learning environment, or task-unit modification), and reaching logical goals (such as successful 3D printing, or overcoming technical problems). Table 9.5 shows the breakdown of next steps that were identified across all reflections. Of note, the variability of references combined with the low numbers of teachers for each code points to the personal nature of each teacher's next steps.

Table 9.5 – Range of Next Steps References in Reflections

| ***Next Steps*** | **No. Teachers (n)** | **No. Teachers (%)** | **No. Coding References** |
|---:|---:|---:|---:|
| *3D Printing* | 1 | 4.2% | 1 |
| *Allowing More Time* | 9 | 37.5% | 19 |
| *Design* | 6 | 25.0% | 11 |
| *Feedback and Discussion* | 4 | 16.7% | 9 |
| *Inquiry* | 4 | 16.7% | 5 |
| *Overcoming Technical Issues* | 6 | 25.0% | 7 |
| *Re-organising the Learning Environment* | 8 | 33.3% | 13 |
| *Revision* | 5 | 20.8% | 8 |
| *Task-Unit Modification* | 3 | 12.5% | 6 |
| *Testing* | 1 | 4.2% | 1 |
| *Trying New Strategies* | 6 | 25.0% | 15 |

However, for the group of nine teachers (37.5%) seeking to allow more time for makerspaces, there was consensus that such time was needed to achieve better results. Hannah stipulated her need for more "planning time", and Jenna stated her need "to have a play around with the app myself". The remaining teachers felt that more time was needed in the curriculum. Mackenzie, Rachel, Sophie, Sally and Tim all agreed that students needed more hands-on time with the app. As Rachel put it, "more hands-on time with the app is required for children to gain confidence and the skills to use it effectively". Mackenzie elaborated that "it is obvious that students need more opportunities to participate in design activities", and Sophie felt that "more time is needed to build students' skills with Shaper". At one point, Sally worried that she was "running out of time to have them have an object ready for printing before the end of the year", and Kirsten noted that in future teaching in makerspaces, she "will allow more time for reflection".

One third of teachers (33.3%) referenced re-organisation of the learning environment, which prominently included re-configuring group work and, to a lesser degree, making better use of the learning spaces available. Amanda, Julia, Madalyn and Mackenzie believed that configuring smaller groups would improve the quality of their students' work, whereas Penny felt that pairs would work best in her classroom. Working in their open-plan team teaching environment, Madalyn and Mackenzie strongly felt that small groups were needed to offset the noise and commotion that comes with having approximately sixty-five students in the one room. In Mackenzie's words:

> I think we should spread out more across the two rooms and each teacher could engage with the same small groups each week to encourage/guide the students. It will make our

> observations of the children more consistent and valid, and we would understand better the type and amount of intervention required to help the students with Makers pedagogy.

Rachel and Ella said they would like to employ peer instruction through more carefully-planned pair work. Rachel reasoned that "perhaps carefully pairing students so that low performing students don't feel so intimidated by the task" could work in her classroom, whereas Ella said she would like "to pair more capable students with the less capable to allow them to help each other refine their designs".

Several teachers referred to issues pertaining to technology use, including technical issues (n=6, 25%), testing (n=1, 4.2%) and 3D printing (n=1, 4.2%). Technical issues were relatively straightforward in nature. Dawn sought to simply use "iPads that work", while Emma, Molly and Tim all wanted to make sure that their iPads would successfully connect to the internet. Madalyn said she would like more iPads because "currently, groups of four-to-five are sharing one iPad, meaning there is a lot of waiting… not a skill that Kindy are good at ;) [sic]". Sally's main technical challenge to overcome was "how to introduce the app to the class". Sophie's main goal was to successfully 3D-print all characters for her class' short story, and Amanda sought to allow a whole lesson "for a final test of our new designs once they have been printed".

Teachers often reflected upon future pedagogies that they would like to use. Future feedback and discussion strategies were raised by four teachers (12.5%), while the same number of teachers referenced inquiry as a pedagogical approach. Alice felt that giving and receiving feedback could be a strong opening activity in future lessons, and Ella thought that an opening class discussion could be leveraged to produce "criteria to refine our toys before printing off a design for each student". Reflecting on the large number of designs in her class, Penny thought she needed to have "a conversation with students about which ones to save". Tim felt that in a future lesson "it would be great if we can spend more time discussing the [design] items and evaluating them as a class". In terms of inquiry, teachers appeared to recognise research as an important next step. Alice said her students "will identify which teacher they would like to design a keyring for and conduct a survey", whereas one of Madalyn's next lessons "will involve students doing more research… and beginning to design an item to put in the tank and keep the [hermit] crab alive". At one point Nadia expressed optimism about the introduction of the unit's problem to her students in the next lesson, feeling that they have been equipped with technology skills needed to explore and design objects in response. Penny had negotiated a set of class iPads for an upcoming lesson, feeling that "they will have an opportunity to work on the app to discover [things] for themselves".

Elsewhere, trying strategies that were new to the individual was a focus area in the reflections of six teachers (25%). Jenna sought to create her own 3D object to model the process and product for her students. Kim wanted to "explicitly teach that things like eyes and a nose needs to be embossed/raised so they can still be seen when they are printed". Mackenzie felt that Lego as a design tool might "engage and motivate students… [who] would be able to design with the blocks rather than share one iPad in a group of four". Penny said she would like to use her interactive whiteboard (IWB) to include "maybe screenshots of students' work, demos of magnet tools and maybe videos from the Makers Empire website". Sally said she would like to try a "free play experiment", where students explore the app for themselves before the teacher "introduces challenges via the document camera". To improve communication skills in his Kindergarten classroom Tim wanted to explicitly teach his students "how to share their ideas".

Six teachers (25%) referenced design as one of their next steps. Emma's students had all prepared shadow puppet prototypes using cardboard and would use these to guide the design process with the *Makers Empire 3D* app. Kirsten's students were given homework to explore the Toy Designer feature of the app and create something unique, while Penny spontaneously decided "to get students to design a submarine using the app and then refine their straw constructions [prototypes] as part of next week's activities". In an early lesson, Rachel was "looking forward to getting the students to planning a simple design and them starting to use the app to create it". Sophie developed a different next step at the end of each of three lessons that respectively involve a focus on flat objects and drawing, interrogating the design problem, and creating the design solution.

Five teachers (20.8%) referenced revision as a next step. Interestingly, in all five cases, there was a perception by the teacher that concepts and skills required revisiting for mastery to occur. Having encouraged her students to openly explore 3D design on their iPads, Ella aimed to "revise what we already know about the app, go through some designs with the class and discuss some positives and negatives about each". Julia felt she needed "to revisit 2D shapes and 3D objects in class maths topics so all are familiar with mathematical language". Mackenzie felt that she and her colleagues hadn't "allowed enough time for students to think, then share, then collaborate and design" and decided that "it would be preferable to revisit each lesson, as this would give the students the chance to evaluate their ideas… [and] the opportunity to rethink, improve and change their initial plans". Similarly, Nadia noted that as her students "gradually progress towards creating their designs in Makers Empire, I need to really consider how to get them to re-evaluate the concept of size". Penny felt she needed "to have more discussion on why the 3D printer would be a good solution to certain problems", proposing that "we could revisit the previous projects and see how a 3D design app and printer may have been helpful".

Finally, task-unit modification was referenced by a small number of teachers (n=3, 12.5%) as an important next step for them. In realising that her students were progressing more quickly than anticipated, Emma felt she should revise her lesson sequence to allow students to move into substantively addressing the problem. Similarly, Kim thought she could "narrow down the areas of the program" to focus more on problem solving skills. Late in her implementation of the unit of work, Sally realised that she must condense her unit of work "to prepare the class for what is happening… and make the app a substantial part of the activities for the next two weeks".

## 9.8 Limitations of the Reflective Journals

This chapter reflects the thoughts, planning, actions and beliefs of the teachers as they implemented their makerspaces units of work. Journals such as these can be powerful tools for revealing teachers' approaches to learning design, maker pedagogies, technology use, and learner support. However, several limitations are noted. First, the unstructured nature of the reflections meant that teachers were selective in terms of which questions they addressed, and this precluded a more systematic and methodical analysis of teachers' response to each question. Second, the overall numbers of reflections per teacher varied greatly, meaning that those teachers who provided fewer reflections also offered a smaller window into their thoughts and practices. Third, some journals included detailed artefacts that further demonstrated and contextualised teachers' ideas in a way that perhaps the written word could not. This meant that the research team could extrapolate further findings where such artefacts were included, but not where they were omitted. Finally, some teachers required additional reminders and encouragement to complete their reflections, sometimes leading to a notable gap in time between when the lesson was taught and when the reflection was written, possibly compromising the accuracy and currency of the reflection.

## 9.9 Reflective Journals: Summary and Concluding Remarks

Despite the limitations noted, several insights emerged, particularly in relation to how teachers used reflection as a tool to identify, understand and overcome challenges. The focus in each of the 102 reflections was very clearly on some form of making and the diverse ways that this making can be achieved. Table 9.2 indicates that both offline and online forms of making received equal emphasis, which broadly aligns with researcher lessons observations. Teachers saw strategies as integral to the outcomes of each lesson, often drawing close connection between what they decided to do, and what emerged because of their decisions. The strategies referenced prominently included explicit and open-ended forms of instruction, with teachers often seeking to incorporate both in the lesson so that their learners could be supported while having ample opportunity to explore. Indeed, most lessons incorporated a range of teaching strategies, including explicit instruction, modelling, open-ended discovery, some form of group work, class discussions, presentations and feedback sessions. There were interesting and thoughtful combinations of these strategies evident in many of the reflections, and these combinations were clearly fit for purpose. Most teachers appeared to draw on explicit instruction at times, usually for guiding students through difficult steps with the Makers Empire 3D *app*. This appeared to go well with modelling – such as with Jenna‘s "model-then-do" approach, which was explicit, incorporated step-by-step guidance and modelling, then provided learners with an opportunity "to do". Class discussions and dialogic discourse appeared very important for promoting meta-cognition and critical thinking.

Although the teachers maintained a positive outlook throughout most of their reflections, many implementations were far from smooth. Challenges were many and various, including technology problems, misconceptions, conceptual challenges, and problem learning behaviours. Given the fact that it is their first implementation of makerspaces units of work, such challenges were normal, and many of the teachers appeared good at solving them "on-the-fly". The reasoning shown in their "next steps" suggested that the teachers in the sample were always thinking of practical, pedagogical solutions to the problems they encountered, with a view to consistently supporting their students and improving learning outcomes.

# PART IV
# Post-Implementation Reflections Analysis

# 10 Student Focus Group Analysis

*Fourteen student focus group interviews were conducted with groups of two or three students (34 students in total). Students explicitly and implicitly identified how the makerspaces activities involved creativity, critical thinking, problem solving, and development of content knowledge through tasks that they saw as relevant to the real world. Students enjoyed the capacity to often direct their own learning in the makerspaces lessons and viewed their learning experiences as an exercise in collaboration. However, some students identified collaboration problems that occurred, and many found the Makers Empire 3D app interface difficult to operate and interpret the interface at some point. Almost all students provided highly positive reviews of the app, and all indicated a desire for more 3D design and printing lessons in future. There were 32 students (94%) who wanted to use 3D design and printing once they left school – for instance, in future careers, or for fun.*

## 10.1 Introduction to Student Focus Group Analysis

This chapter presents the analysis of students' insights on their makerspaces experiences, as explored in the focus group interviews. The protocol and questions discussed, followed by a summary of key descriptive statistics. The inductive coding methodology used to analyse the data is then explained, before concluding with a discussion of the five first-order themes that emerged during the analysis: (1) *Learning Outcomes;* (2) *Learning Behaviours;* (3) *Challenges;* (4) *Students' Thoughts on Making;* and (5) *Next Steps*.

## 10.2 About the Student Focus Groups

After the completion of the units of work, two researchers conducted interviews with focus groups of 2-3 students from the same classes where in-depth video screen recordings were taken. During these interviews, the researchers encouraged students to talk about their experiences with makerspaces, explain highlights and challenges, and discuss possible next steps in in their making. The interviews were semi-structured in nature, drawing on ten initial questions (also found in Appendix 5):

1. Can you tell us about what you made? What problem did it solve? Why did you make it the way you did?
2. What did you learn from creating your product?
3. What did you enjoy most about making your product? Was there something you didn't enjoy?
4. What was most difficult about making your product?
5. Did you like using the *Makers Empire 3D* app? Why or why not?
6. What made the *Makers Empire 3D* app easy or difficult to use? Can you suggest any changes?
7. Do you think you like school more or less after the maker activities? Is school more interesting/enjoyable with maker activities? Why?
8. Would you like to do more activities like this in your future classes?
9. Would you say that you are a good 'maker'?
10. Would you like to be a maker (engineer) when you grow up?

To make students comfortable and promote discussion, researchers initially asked those in the first three focus groups to bring either their 3D-printed object or iPad designs. Researchers observed that with or without the objects in the room, students could easily recall their makerspace experiences and describe objects they had made. In total, 14 interviews took place, ranging in length from approximately eight minutes to 20 minutes, with an average length of approximately 12 minutes. As outlined in Table 10.1, eight interviews occurred with pairs of students, with the remaining six interviews conducted with groups of three students. 34 students were interviewed in total, which included 16 Kindergarten students (47.1%), 12 Year 1 students (35.3%), and six Year 2 students (17.6%).

As with other qualitative data in the study, the data was explored inductively through segmenting, coding and the creation of category system of first- and second-order themes. There was similar overlap of ideas across the students' responses to the questions. In particular, the use of double- and triple-barrel questioning meant that very often, students explored several ideas in response to each question, and developed these ideas further in responses to subsequent initial questions and/or follow-up questions. The inductive approach therefore enabled the research team to accurately capture, code, and enumerate all the ideas discussed in the interviews and present these ideas thematically.

Table 10.1 – Student Focus Group Descriptive Statistics

| *Average length:* | **00:12:17** |
|---|---|
| *Max:* | 00:22:33 |
| *Min:* | 00:07:52 |
| *Total Minutes:* | 02:52:02 |
| *No. Interviews* | 14 |
| *No. participants interviewed* | 34 |
| *Average focus group size:* | 2.4 |
| *No. Kindergarten students* | 16 |
| *No. Year 1 students* | 12 |
| *No. Year 2 students* | 6 |

Table 10.2 shows the category system that emerged through inductive analysis, with five first-order themes, including: (1) *Learning Outcomes*; (2) *Learning Behaviours*; (3) *Challenges*; (4) *Students' Thoughts on Making*; and (5) *Next Steps*. Column 2 (Number of Coding References) provides an indicator of the frequencies with which the themes occurred in the data, while Column 3 (Number of Words Coded) provides an indicator of the level of detail provided across the responses.

Table 10.2 – Coding Structure Employed in QSR NVivo (Version 11)

| ***Code*** | **No. Coding References** | **Number of Words Coded** |
|---|---|---|
| *Learning Outcomes\Content Knowledge* | 14 | 545 |
| *Learning Outcomes\Creativity and Imagination* | 52 | 2,468 |
| *Learning Outcomes\Critical Thinking* | 47 | 2,458 |
| *Learning Outcomes\Problem solving* | 46 | 2,322 |
| *Learning Outcomes\Real World Connections* | 20 | 1,412 |
| *Learning Behaviours* | 48 | 3493 |
| *Socio-Emotional Behaviours\Autonomy* | 24 | 951 |
| *Socio-Emotional Behaviours\Collaboration* | 24 | 1,029 |
| *Challenges* | 63 | 2,464 |
| *Challenges\Difficult* | 43 | 1,763 |
| *Challenges\Easy* | 20 | 701 |
| *Students' Thoughts on Making* | 168 | 6,144 |
| *Students' Thoughts on Making\3D printing* | 5 | 201 |
| *Students' Thoughts on Making\Aesthetics* | 13 | 477 |
| *Students' Thoughts on Making\Complete Product* | 37 | 930 |
| *Students' Thoughts on Making\Functionality* | 28 | 1,022 |
| *Students' Thoughts on Making\General Views on Making* | 16 | 402 |
| *Students' Thoughts on Making\The App* | 67 | 2,789 |
| *Next Steps* | 61 | 3,439 |
| *Next Steps\Home* | 13 | 779 |
| *Next Steps\Post-School* | 37 | 2,178 |
| *Next Steps\School* | 11 | 482 |

## 10.3 Theme 1: Students Discuss Learning Outcomes

Question 1 ("Can you tell us about what you made…?") and Question 2 ("What did you learn from creating your product") were of primary relevance when exploring learning outcomes. However, responses to other questions such as Question 3 ("What did you enjoy most…?") and Question 9 ("Would you say you are a good maker?") also proved useful. Coding references were evenly distributed between the second-order themes of "creativity and imagination" (52 references), "critical thinking" (47 references) and "problem solving" (46 references). As Table 10.3 shows, however, the number of students making these references differs considerably across the data, with almost all students referencing creativity and imagination, approximately three quarters referencing problem solving, and approximately two thirds referencing critical thinking. Slightly more than half of the students referenced real world connections, while just over a third referenced content knowledge.

Table 10.3 – Range of Learning Outcomes Referenced by Students in Discussions

| ***Learning Outcome*** | **No. Students (n)** | **No. Students (%)** | **No. Coding References** |
|---:|---:|---:|---:|
| *Content Knowledge* | 12 | 35.3% | 14 |
| *Creativity and Imagination* | 30 | 88.2% | 52 |
| *Critical Thinking* | 21 | 61.8% | 47 |
| *Problem solving* | 25 | 73.5% | 46 |
| *Real World Connections* | 18 | 52.9% | 20 |

Thirty students (88.2%) referenced creativity and imagination in diverse ways. For some students, such as Charlotte and Polly, this involved the creation of a narrative around the made object:

> Polly: We made a cubby house.
>
> Charlotte: Inside, we made a kitchen, so we can cook inside.
>
> Polly: And also on the second floor – we have three floors – the second floor we have a pool. And a bedroom so we can relax in the bedroom and go to sleep. And also in the pool you can splash around. And we have extra swimming clothes.
>
> Charlotte: And on the third level we have a garden, so people can plant food and we have a soccer area. And if it was real, we would be like, splashing inside, and it's all right if we get wet because there was a changing room and then we can change back into our uniform.

For other students, characters appeared to come to life and play out stories. For example, Sandy stated that her character was "going to be friends" with other students' characters, while Melanie planned to build a castle for her and her friends' characters in which to live. Jayde said she would like "to make an octopus… to put in a story with the sea… [with] also fish in there", while John wanted "to make a big city… using boxes and those things [in Blocker]". Some students such as Damien and Nicholas described objects that have been adapted and remixed from ordinary everyday objects. Damien's soccer shoe had "little spikes that you can fall under… and using one of them, you can actually lock time". Amanda was fascinated by "opposites" and said she would seek to make things "that are opposite" in future to objects that exist in the present.

Twenty-five students (73.5%) referenced problem solving when discussing their approaches to making. What was particularly interesting about this group was, however, that it included almost all 21 students (61.8%) that referenced critical thinking in their discussions. In many cases, the research team coded data segments with both "problem solving" and "critical thinking", finding that as many students explained how they solved problems in the making process, they demonstrated critical understanding of one or more aspects of the task they undertook, such as the topic area, materials used, the *Makers Empire 3D* app, and the making process in general. For example, Denise and Macie both explained their understanding of size and proportion when using the app, which emerged from having to ensure that they could move and connect objects:

> Denise: And this has to be the same size as – all of the things has [sic] to be the same size because if we don't move it, it's going to be like something like a blob. So we can move it properly. That's why we have to have it the same size. If it wasn't at the same size, we won't know what this is.
>
> Macie: And also, if it's not the same size like this, because this one is so up, then when if you move it like this, this pick, this part over here will look a bit more thicker. Because if there'd be more thicker over here.

Elsewhere, students could articulate their critical understanding that had emerged through solving different problems. Aaron was excited to learn about buying and selling, explaining that he liked to buy objects to "stick on" the boat that he was making for his assignment, and observing in one case that when he made these objects "stick together, it can be a wave boat [able to withstand waves]". David described how a friend miscalculated size and shape when building a boat, when they "got a big part of a wall, and then they did a long wall, and their boat was sinking down, and they brought in [joined the walls to make a boat]… but our character will never fit there". Coby described a similar process, where he had learned how to use the Blocker feature of the app to build his boat: "when you press the button… it makes a little block and you can… when you do this it's nice, like when you slide it on your finger it just slides". Jayde described the challenge of building a shadow puppet, when she made "these two hands the same and I reflect it to the other side... and this one I did the same to reflect it the other side too… then I add this little thing, so we can hold it [the puppet]". Baker described creating a puppet owl by putting "the beak behind this [body], so I made it hidden, and I used tape right here, and made it turn around to make a hook so it can fly". Rodger explained his understanding of duplicating components in the app when creating an object for his hermit crab: "we put a block and there's, like a rectangle thing, two rectangles… and then it copies it, it makes a copy out of it and then you can put that other block next to it".

For the 18 students (52.9%) referencing real world connections, these connections often lay between the topic they studied, the object they made and the scope they saw for similar making in the future. Referring to his "wave boat" model, Aaron believed that speed remained a challenge for his future designs: "it can float, and well it looks like a real boat… but sometimes real boats can go even faster". Anthony made a snowman, so he could "enter it in competitions… and it's also nearly Christmas… so I decided to make something Christmasy… and it might snow in China, and I was born in China". Samantha decided to make a pool for her pet hermit crab that "can climb on in… drink and have a bath". In other cases, several students identified the use of tokens and the commerce around buying and selling objects as vehicles for real world connections. Polly argued that she and her friends "want to save up more money [tokens] to buy things… so if we have like 1000 dollars, we can like press on everything and make anything!". Randy loved the fact that he could "make shapes and put them on [online] for people to buy", whereas Damien believed that when he grows up, he will “make toys… and we can sell them to kids and then we could have money”. Samantha saw an opportunity to make houses in the future “in case people don’t have a house... I’m going to rent lots of houses, so people can stay in them... When everyone has a house, I can build my own house”.

In contrast to the other second-order themes in the *Learning Outcomes* category, only 12 students (35.3%) referred to content knowledge in their discussions. Aaron recognised the reasons for testing his boat in a bucket of water with a figurine, “because real boats float”. Denise similarly recognised the need to test her shadow puppet fox through motion and light so that they it work in the final performance: “the fox has to run from the mouse because it thinks the Gruffalo’s going to eat it… so, this fox saw the Gruffalo, that’s why it’s going to run like this [demonstrates]”. Rodger, Ray, Samantha and Hayden all learned about the survival needs of hermit crabs – as Rodger puts it, “…about them eating corn and having a shower”. Ray learned about the important distinction between freshwater and saltwater, having two 3D-printed baths for his hermit crab: “there’s one, water, that’s salty water to take a bath with… and there’s another water, that’s just fresh water to drink”.

## 10.4 Theme 2: Students Discuss Learning Behaviours

Only two learning behaviours were clearly referenced in the students’ responses to the questions asked – namely, autonomy and collaboration. The research team indirectly identified these learning behaviours mainly through Question 2 (“What did you learn…?”), Question 3 (“What did you enjoy most…?”) and Question 10 (“Would you like to be a maker when you grow up?”).

Eighteen students (52.9%) referenced autonomy in their discussions. In many cases, they framed autonomy as about freedom, choice, and creative license. Sandy said she would love to make a castle for her characters and hoped that her teacher would allow this in future. Aaron was proud that he could engineer his boat design to withstand waves “all by myself”. Melanie liked the *Makers Empire 3D* app “because you can make anything”, and noted that when she grows up, “I will just build anything that I want”. The sentiment of making anything and/or everything was reflected in other students’ comments, such as Amanda’s, who “in the future… will just make everything” and Macie, who said she would like to improve the *Makers Empire 3D* app to the point where “you could just draw anything you like, like girls and boys”. Lindy wanted to “make anything we like” while Rodger enjoyed using the app because “we can make anything”. On the other hand, Denise seemed disappointed that she had only been able to work with the Shaper tool in the app, and wanted “to do anything that we want, not just shapes”. Likewise, Charlotte said she would like to make objects where she didn’t “just need to use shapes” and wanted “to use other shapes… like where we press something and there’s more shapes”. Randy believed that the app “should let people make their own shapes to doodle on”, while Samantha felt that the app should allow students to change colours and 3D-print objects with the selected colour. Nicholas observed that if he could make anything, he would “just make cool stuff”. Rodger believed that choice about what to make should be a reward, “if we were working hard”. Charlie wished “that you could just say what you wanted to make and then it [the app] makes it”.

Nineteen students (55.9%) indirectly referenced collaboration throughout their discussions. The framing was very often “we”, as students described what they made, often with close reference to other students in the focus group and classroom. Students also readily added to responses given by their peers, and the dialogue that unfolded in several cases showed the nature of collaboration in the concerned. For example, Denise and Macie explained how they worked together to build their shadow puppet:

> Denise: I found hard that how are we going to make this back, because...
>
> Interviewer: The back?
>
> Denise: No, these ears. Because this one is up and this, one of them are up, one of them are down, so I did not know how.
>
> Interviewer: OK. You have an up ear and a down ear, how do you do that? That's tricky.
>
> Denise: We go on the site then we can see up and down buttons, and Macie accidentally made me [click one button]. It was already up but it had ended down.
>
> Macie: And Denise did the little thing over. Like that little thing, but bigger.
>
> Denise: I did the face.
>
> Macie: Yes, she did the face over here, and I did the ears… and she did the little body.

Rabia described open-plan, team-taught lessons where "Kindergarten and Year 1 worked together", adding that she liked the arrangement "because it was fun". Describing the same classroom structure, however, Emmanuel conceded that at times, his "group wasn't working as a team… they were fighting", to which Talbert and Samantha added "it's the same thing for me". Other students referenced a more knowledgeable peer who helped them overcome a problem, such as when Lana showed Rabia how to combine shapes, or when Jayde's older brother helped her with the *Makers Empire 3D* app at home.

## 10.5 Theme 3: Students Discuss Challenges

In contrast to the typically indirect references to learning outcomes and learning behaviours, students most often referred directly to what they found difficult in response to Question 4 ("What was most difficult…?"), and what they didn't enjoy in response to Question 3 ("…was there something you didn't enjoy?"). These two questions were, therefore, of primary interest when exploring what students found both easy and difficult in the making process.

Over four fifths of the students (n=28, 82.4%) could clearly articulate the challenges they faced. For Melanie, Sanita, Nicholas, Emmanuel, and Aaron, successfully joining components of the object was the main challenge in the design process. When designing her princess, Melanie complained that "the crown might be cheeky and fly all over the place", whereas Sanita found it difficult to put glasses on her character, "because I am trying to put the wings and the glasses on, but I have a very easy idea for the wing, but not the glasses". Nicholas observed that during the creation of his character, "everything went messed up because when I was trying to draw the wings, it didn't [do] it right… it just went down instead of going where my finger was going". Emmanuel stated, "it is difficult to put another block on top of others", while Aaron concluded, "when they [the components] stick together, they look funner and funner [sic], but if they don't stick together, that means it's not fun". Both Sandy and John appeared to be a little overwhelmed by their experience of the app, with Sandy observing that her object "keeps twirling around and going under" and John conceding that he "keeps on getting confused" because his partner Edward used "spinning to spin it [the component] the other way… so the head isn't outside the square". Coby was concerned about the "bomb icon", which could, when pressed, result in accidental or intentional deletion of the design. Macie found combining intricate components such as facial features difficult, because "sometimes you can't put the head [in the right place], and then it comes a little thing over here… and for the nose it's hard because you can't make it so short". Both Rabia and Jayde expressed the difficulties of correctly sizing and proportioning their designs. As Jayde put it, confusion could emerge from not being able to size objects accurately in the design: "these little features [components] are not in the same space… one is too under [small] and one is the same [size]… also, but these two hands, this is bigger than this one, or this one's smaller than that".

By contrast, 16 students (47.1%) referenced aspects of the making process that they found easy. Melanie noted that creating a fidget spinner character was very simple: "what's easy is to get the blob and put the glasses on, then put the wings in the fidget spinner on". Aaron found the challenge of creating buildings very straightforward and thought, "…in Shaper you can make a castle... [because] it has a cone on top, and a castle has, maybe I can put a rectangle in there [the design]". Sanita admitted that using the Blocker feature of the app – which was required for her boat design – "is too easy for me" and sought a task that more challenging. Both Amanda and Coby found the Toy Designer feature of the app very easy, with Coby suggesting that it lacks challenge because "when you press the thing [option], you just… it will be there, and I kind of don't like that" and concluding "I like Blocker more than Toy Designer". For Edward, John, Polly and Damien, however, the *Makers Empire 3D* app represented middle ground in terms of the level of challenge. Edward described this level of challenge as "just normal", while John said the software was "not really *very* easy… just easy". Although she recognised numerous challenges in the design process, Polly maintained that the software was "a little easy", whereas Damien regarded it as "medium" in difficulty.

## 10.6 Theme 4: Students Discuss their Thoughts on Making

Theme 4 explored how students saw their making, including several attributes they regarded as important, all of which are outlined in Table 10.4 below.

Table 10.4 – Range of Students' Thoughts on Making in Discussions

| ***Learning Outcome*** | **No. Students (n)** | **No. Students (%)** | **No. Coding References** |
|---:|---:|---:|---:|
| *3D Printing* | 5 | 14.7% | 5 |
| *Aesthetics* | 7 | 20.6% | 13 |
| *Complete Product* | 34 | 100% | 37 |
| *Functionality* | 18 | 52.9% | 28 |
| *Maker Efficacy* | 26 | 76.5% | 18 |
| *The App* | 32 | 94.1% | 67 |

Of note, the *Makers Empire 3D* app ("The App") received much attention in their discussions, with almost all students referencing how they had used the app to support their making. The "Maker Efficacy" code reflected how they saw themselves as makers, which Question 9 directly informed ("Would you say that you are a good maker?"). The "Complete Product" code captured references to the complete products that students had successfully designed and 3D-printed and was informed by the first part of Question 1 ("Can you tell us about what you made…?"). The "Aesthetics" and "Functionality" codes identified aspects of the products that were aesthetic or functional in nature, with these codes largely informed by the third part of Question 1 ("Why did you make it the way you did?"). "3D Printing" captured students' references to 3D printing.

Almost all students (n=32, 94.1%) were keen to discuss their thoughts on the *Makers Empire 3D* app, with commentary that included what they liked about it and what they felt can be improved. Several students – including Melanie, Philip, Samantha, Ray, and Emmanuel – really enjoyed using the app, and did not believe it needed to be improved. Melanie argued that "nothing is bad" when it came to using the app, while Philip gave the app "11 out of ten" as a score for how much he enjoyed using it. Samantha and Ray similarly liked the app "100%", whereas Emmanuel used the expression "from zero to infinity" to emphasise how much he enjoyed using it. Aaron and Coby both observed that working with two- and three-dimensional shapes was fun, while John and Anthony enjoyed "levelling up" after completing challenges and tutorials. Melanie simply enjoyed the fact that with the app, "you can create anything", while Anthony was proud of the fact that the snowman he submitted to the online portal "now has 36 likes". For Samantha and Rodger, using the app to design objects they could provide their pet hermit crab was satisfying, as Samantha puts it, "…like we can print it [the design] and we can see it and we can put it in the hermit crab's tank". Melanie, Charlotte and Ashley described their enjoyment using the app in further detail. Melanie commented on the fun that she had overcoming challenges and creating authentic objects with the app: "the challenges, I think, you can do… and you can make characters and you can also have fun creating… and you can learn things, like for making shadow puppets". Charlotte felt that the app "makes us really creative, and then we can like design our own things and print them out", whereas Ashley's enjoyment stemmed from making "pretty much a lot of designs in Blocker… and I 'blockify' a lot of pictures and things". Several students believed that using the app to design and 3D-print objects had made school more fun for them relative to school without the *Makers Empire 3D* app. For example, Sandy stated that she now liked "school 90%, and *Makers Empire* like, 100%", whereas Aaron stated that he liked "*Makers Empire* 300[%], and school 200[%]".

In terms of suggested improvements, Benson said he would like to see "more shapes… [and] new shapes" available to him in the design process. Denise, Charlotte and Damien felt they had been somewhat limited by a task that involved mainly working with shapes and said they would like to see more options to design beyond this – in Charlotte's words, "so we can choose different things and we just don't need to use those shapes". Polly, Randy, Damien and Anthony all had concerns about the buying and selling options within the app platform. Polly simply believed that all objects in the shop "should be free", while Anthony pointed to a problem with the app platform that he saw as inherently unfair: "if you buy someone's design and it's for free, but someone sets it for 35 tokens, then you still lose the tokens". A discussion between Damien and Randy about tokens, jealousy and levelling up suggested a degree of frustration with how they see progression in the app's online platform:

> Damien: *Makers Empire* sometimes like it needs like… the money – it's like people can be jealous how much money and then… [pauses]
>
> Interviewer: Do you have a solution for that?

> Damien: Maybe we could like have no tokens and then just have levels… and then when we go up to a certain level, maybe we can have like six tokens or something.
>
> Interviewer: That makes sense. Randy, is there anything else that you think?
>
> Randy: Maybe you should like make a lot of items that you can get because you have to like buy the items that you want because when you need something, and you have like no tokens, you might not be able to buy it.

While she enjoyed using all the features of the app, Charlotte said she would like to create "our own app for making", whereas Samantha said she would like colour customisations to be 3D-printable.

All 34 students (100%) referenced complete products that had been designed and 3D-printed as part of their study. A number of these students created products together, while remaining students referred to products they had made by themselves. Table 10.5 shows the range of objects referenced in response to Question 1 ("Can you tell us what you made…?"), taking the students' first answers as the main object they designed and 3D-printed. The objects fell into five main categories, with the two most common categories "two-dimensional characters" – all of which were created for a Year 1 unit of work on shadow puppets – and "building models", which consisted of models created for a Year 2 unit of work on playground sculptures, and models created for a Kindergarten/Year 1 combined unit of work on the living needs of hermit crabs. The "boats" category included boats that students created for a Kindergarten unit of work on buoyancy, whereas the "three dimensional characters" and "toys" categories included an assortment of objects that students made for introductory activities and/or in their free time.

Table 10.5 – Range of Complete Products (Categories and Examples) in Discussions

| ***Complete Product (and Examples)*** | **No. Students (n)** | **No. Students (%)** |
|---:|---:|---:|
| *Three-dimensional characters (fairy princess, man, woman,* | 5 | 14.7% |
| *Two-dimensional characters (shadow puppet)* | 9 | 26.5% |
| *Boats* | 4 | 11.8% |
| *Building models (cubby house, shelter, castle, house)* | 9 | 26.5% |
| *Toy (log, 3D shape, soccer shoe, toy box)* | 7 | 20.6% |

The complete products could be further understood through students' references to "aesthetics" (n=7, 20.6%) and "functionality" (n=18, 52.9%). For the eight students referring to aesthetic dimensions of their designs, colour, detail, size, shape and the ability to connect varying components were all important concerns. Melanie's main goal for her "fairy princess" was to "be pretty", and she said that she will seek to make aesthetically pleasing toys for other children when she grows up. She was concerned that the printing process did not allow colours to be printed, said she would like to make her object "rainbow coloured" and "have love hearts". The main design challenge for her was connecting the crown to the head of the character. Sanita shared this concern when adding wings to her character, while her partner David found it relatively easy to "make a pointy nose [on the character's head] and put some eyes on it… and a hat" so that "he looks kind of cool". Macie and Denise both enjoyed working with the at-times intricate parts of their shadow puppets, as Macie put it, continually "looking and checking what it looks like". Jayde was proud of her mouse shadow puppet, which she regarded as "really cute and pretty", being particularly pleased that she "made its two hands really small". Sandy was very excited to be painting her 3D-printed character pink.

The 18 references to functional aspects of the designs reflected three main areas of focus in the units of work that teachers designed and delivered. For Denise and Macie, the complexities of designing and printing operational shadow puppets were evident. For example, Macie explained the different parts of her puppet before demonstrating the actions: "these things [handles] are where you have to hold it, and then this is where it runs… these are its bat wings… then we can move it like this". Discussing the need for the puppets to work properly, Denise described how the fact that she and her partner "love to make shows and plays" motivated her. For others, such as Amanda, although there was the requirement that 3D-printed boats should be buoyant, the class treated the experience of failure as an opportunity to learn:

> We all went out in the garden next to the school and we got a tub and put water inside, and then we tried all our boats… and then, first we tried them by themselves, and then we tried them with teddies inside, but my boat didn't carry the teddy because it was too heavy.

Elsewhere, students such as Samantha, Lana and Ray needed to design functional objects to meet the identified needs of living things. Samantha had designed a stepped log "so the crab can climb on it, and when the crab is tired, he can lie on it". Lana had also designed a house that is appropriately-proportioned: "I made a shelter, but the hermit crab was climbing in it... and I made a hole in it, so the hermit crab could crawl through and I thought it wasn't big enough but… it was big enough for the hermit crab to crawl into like pooh!". Ray discussed working with different shapes to create a bowl for their hermit crab: "we also made, like, a flat shape under it for the base and then we put a circle on top of it… it's a 3-D shape and it's like a circle... and then we just tried making a bowl out of that".

For the small number of students referencing 3D printing in their discussions (n=5, 14.7%), the presence of the 3D printer in the classroom seemed to serve more than its ostensible purpose. Samantha and Lana implied that the 3D printer was a tool to "test" the effectiveness of the design – in particular, whether the size of the object was appropriate. Describing her first time printing, Samantha explained that she was very keen "to see the hermit crab and the 3D printout [interacting], so I can see it [the object] and put it in the hermit crab tank". Similarly, Samantha described the process of interpreting the size of 3D objects in the software and using the printed objects to inform the design process iteratively: "the iPad is small, and the things are big, but when we press on them, they're little but when they come out they're big, but we can make them smaller". Lana also described a trial-and-error process for building a shelter for her hermit crab, where "the 3D printer just printed it [the object] out, and it was big enough [for the hermit crab]". For Denise, 3D printing was as an intermediary step in the design of the object, observing that she "liked it because the *Makers Empire* [software] could print it in this 3D printer… and we get to even paint it!". For Talbert, the 3D printer was the final step "when we've made our ideas and we finish it [the designs], then it will make itself".

Twenty-six students (76.5%) discussed their efficacy as makers, largely in response to Question 9 ("Would you say that you are a good maker?"). For the most part, their discussions were limited to summative judgments of their abilities, and most students presented a positive picture of their efficacy. For example, Melanie said that she was "a great maker", while Macie gave herself "ten out of ten" for her abilities. Similarly, Lana and Rabia were both "really good makers", and Anthony and Ashley gave themselves "nine out of ten". Elsewhere, students offered reasons for their judgment, such as Jayde, who said she was "a great maker… because every Sunday and Saturday, my brother always teaches me…", and Samantha who was "a good maker and a good painter", and "good at building everything". Only a small number of students, such as Nicholas, Randy and Cherie were more circumspect in their assessment. Nicholas conceded that he was "not yet" a good maker and required further time and commitment to improve. Randy rated his ability as "five out of ten", while Cherie thought she was only "a little bit good".

## 10.7 Theme 5: Students Discuss Next Steps

Finally, the *Next Steps* theme explored the contexts in which students felt they could further develop their knowledge and skills as makers. Students clearly referenced three contexts in their discussions – namely, "home", "school" and "post-school". Students' references in these areas were mainly in response to Question 8 ("Would you like to do more activities like this…?") and Question 10 ("Would you like to be a maker when you grow up?").

For the students discussing making at home (n=8, 23.5%), there appeared to be a combination of further experimentation with the app, collaboration with siblings, parents and/or guardians, and connection with similar making applications. Six students – including Aaron, Jayde, Baker, Charlotte, Polly and Anthony – had all installed the *Makers Empire 3D* app on a personal device at home. Except for Anthony, who played with the app by himself, all these students collaborated with at least one other member of their family. Aaron was excited to "have an iPad at home", which he planned to use to design a character that can be 3D-printed and painted. Jayde was particularly good at the Blocker feature of the app, "because my brother taught me that", while Baker sometimes worked with his brother "because he has it [the *Makers Empire 3D* app] and he makes stuff about Minecraft". Charlotte had the app "at my home, and my dad really likes making things", and found her father's support invaluable "because when I try to pull it [the object] through and turn it around, it keeps on like not connecting to the parts". Polly worked with her brother to design objects, and they were encouraged by their parents who "want me to make more things to be so creative". Her mother also helped her "when we were making animals, [because] I couldn't do the spike for a hedgehog… I was going to make a hedgehog, so I asked my mum to help me do the spikes".

Significantly, all students that were interviewed (n=34, 100%) indicated that they would like to continue using 3D design and printing technologies in their future classes and lessons in school. Of these, eight students (23.5%) explained how they would like to engage in their making. John said he would like to make objects that are "bigger and better", further developing this idea by offering "something using boxes and those things… like, a big city...". Polly and Charlotte saw making as closely connected with their creativity in general and said they would like to continue using the software and hardware, in Polly's words, "because we like making moulds and we like being creative". Damien believed that, in future lessons, "we can build our own things and then build something that can make the school better", to which Randy offered the suggestion of objects that provide "more shade". Sandy wanted to extend on the characters she, Melanie and Aaron had created, declaring that in future lessons, she was "going to make a rainbow, and I'm going to make all the things rainbow [coloured], and my little character is going to be friends with Melanie's one and Aaron's [one]". For Ray, simply having more choice in what to make was an important goal in future learning: "I wish, when we go to Year 1, [the teacher] would say 'they're big – let's do anything we want for them' [let them create what they want]… and we can just say, 'make us a phone!'". Melanie echoed this sentiment, stating that if her future teacher allowed her to do so, "I would just make anything I want".

Finally, post-school interests in making were expressed by almost all students (n=32, 94.1%) with 24 of these students (70.6%) explaining their interests in further detail. These explanations fell into two main groups: (1) an apparent desire to make practical day-to-day objects such as buildings, clothing, jewellery and toys; and (2) an apparent interest in working specifically as engineers, often with a focus on creating less conventional, unusual and perhaps even innovative objects. For students in the first group, there appeared to be a strong sense of the intended audience and purpose behind the making. For example, Denise was passionate about the idea of making clothes and jewellery for her friends, family and the public, and believed that she could "give them some choices [in terms of colour, style, shape, etc.] and we make them in the *Maker's Empire* app". She also believed in consulting with her future clients by asking "people 'do you like these coloured clothes?', and if they say 'yes', we can make the clothes". Concerned about the cost of cosmetic products, Macie declared that she would use her knowledge and skills "to make the nail polish cheaper and be a fashion designer". Charlotte loved animals and saw herself becoming a vet, believing that she could "use the [*Makers Empire*] app to make things to help animals, like a toy, because I [already] made a toy ball for my dog". Coby said he would like to use 3D design to "make a really safe [secure] house", and Talbert said he would like to similarly make "a really big house… so lots of people can live there". Referring to his concern for the homeless, Randy felt that he could "build houses so like… maybe people living in the street can have houses for them to get and live in". In terms of the second group, there seemed to be greater awareness of the potential for making beyond the already conceivable day-to-day objects that the first group discussed. For example, Anthony was going to "make some more advanced things like a seven-decker maze…. [where] you have to go to the middle to climb up the ladder to go up to level two and then to level three… and when you get to level seven, you have to go through the maze and find the finish line". Nicholas was keen to make "an ice gun" capable of freezing people in time. Intimating his concern for those with a disability, Rodger said he would like to design "a robotic hand… that can collect it for him [be used by those with a disability to collect object objects]". Hayden thought that he could invent "a new musical instrument".

## 10.8 Limitations of the Student Focus Groups

It is important to note that the young learners interviewed did not use consistent language when describing their experiences with makerspaces, which meant that similarities between nodes were not always related to the specific words used.

During the interviews, it was apparent that some students struggled to answer some of the questions, requiring the use of follow-up questions that were re-worded and/or simplified. For example, for those students who were unsure of what they learned from creating their product (Question 2), follow-up questions probed the specific topic, such as "Did you learn something about hermit crabs? What was that?" Where researchers used these questions, their intention was help the student focus on a specific aspect of their makerspace experience rather than to lead them in their judgment of the experience. However, the reliance at times on more specific follow-up questions when students were faltering to answer the initial questions meant that some students were perhaps at times led in their thinking by the researchers, or by their peers.

Finally, there was a heavy emphasis in these discussions on the *Makers Empire 3D* app, and less of an emphasis on makerspaces in general. Students very often chose to concentrate on the app when answering questions, and although the researchers attempted to re-calibrate the focus to be on makerspaces generally where possible, much of students' commentary remains focused on their experience when using the application.

## 10.9 Student Focus Groups: Summary and Concluding Remarks

The analysis presents students' insights on learning in makerspaces. It explores how they saw the impact of making on their learning outcomes and behaviours and provides their important first-hand accounts of the challenges and opportunities they face. The insights students shared also provide a window into how they view the making process and its relevance to their lives at school, home, and future careers. Students appeared to recognise the knowledge and skills they develop through making, including content knowledge across a range of topic areas, the technical skills mastered through using the technology, and the practice of 21$^{st}$ century skills and learning behaviours such as collaboration, autonomy, critical thinking and problem solving. In terms of the latter, the connection between critical thinking and problem solving was particularly strong, with students using problems as vehicles to think critically – both in-action during the making process, and on-action afterwards, as they reflected on what they learned. Students were also able to form real world connections, particularly between the content they studied, the design process, and the making they saw as part of their future careers.

In terms of learning behaviours, students clearly referenced the role of collaboration for both supporting and underpinning the making process. The examples they provided – namely, collaboration with peers in the classroom and siblings, and with parents and/or guardians at home – suggested that making could improve their collaboration skills, but that utilising the skills was often a necessary steppingstone for solving complex or perennial problems, such as when students drew on the expertise of a more knowledgeable sibling at home. In contrast, collaboration in the form of structured group work did not always lead to intended outcomes, with students being particularly critical of working with peers in large spaces. As the other learning behaviour explored in this analysis, autonomy appeared to be a very strong theme that suggests makerspaces may trigger students' desires for greater autonomy when learning in the in the classroom, and in their future learning beyond the classroom. Many students were intent on making objects that they desired to make, and these objects were not necessarily those prescribed by the task or teacher. For students like Melanie – who declared that, "in the future, I will just build anything I want" – makerspaces can arguably be a vehicle for imagination, self-expression and ownership of learning.

When it came to challenges, students found that the iPad app presented numerous, albeit small, challenges, and that they could overcome these challenges with time, support, guidance and practice. Specific aspects of the process that were challenging included mainly working with the intricacies of proportion, size, shape, and joining objects in the 3D design software. The 3D printers were particularly helpful in this respect, as not only ends in the process, but also as tools for testing the veracity of the design and modifying it further to suit need and context. However, several students were keen to point out that some of the tasks presented design challenges that were too easy for them, suggesting that a more challenging problem or design process may have been appropriate in future learning designs.

Students' thoughts strongly reflected their enjoyment of the *Makers Empire 3D* app and online platform, which most saw as integral to the making process. They appeared to love experimenting with different features in the app and find the process of designing and printing 3D objects to be enjoyable and rewarding. Students understood the need for aesthetic and functional attributes of the objects they designed, and readily connected the object with its purpose in the wider world. The findings on maker efficacy suggest that they viewed themselves positively as makers, and both success and failure informed their efficacy. Although students were very proud of what they successfully made, they were also proud of designing objects that did not meet their intended needs, such as the boats that could not float, and then explaining how they used failure to improve their metacognitive and reflective thinking skills.

Finally, the next steps that students discussed affirmed their keenness to continue learning in makerspaces. Perhaps more pertinently, the discussions about post-school making showed their passion to make objects connected with the world they inhabit. These objects often addressed problems that the students perceived – such as homelessness, disability, or the high cost of certain products – and students appeared to believe that their future making may be able to address these problems. The findings thus suggested that the makerspaces in this study supported authentic, situated learning, and that students were becoming aware of how they could put their knowledge and skills to use in the future. The focus on real world problems and potential design solutions in the interview data appeared to embody Design Thinking – an important feature of the professional learning program – particularly with its emphasis on integrating authentic problems and encouraging the ideation, prototyping and evolution of a range of solutions to the problem. With a positive outlook on their maker efficacy, enthusiasm with the tools available, interest in real world problems, and creative capacity, the students in the study appeared well positioned for the learning ahead of them.

The strong student support for makerspaces was reinforced by the 32 (94.1%) student interviewees who wanted to continue using makerspaces in the future. Interestingly, one school had asked the broader body of student participants whether they wanted to undertake makerspace-based 3D design and printing tasks in future using the *Makers Empire 3D* app, and 292 out of 297 students (98.3%) indicated that they would. This high student demand to continue with makerspace-based 3D design and printing in future provides a pertinent indicator of utility and satisfaction.

# 11 Post-Implementation Questionnaire Analysis

*A post-implementation questionnaire was issued to teachers after they had completed their makerspaces modules. Teacher confidence to teach in makerspaces had improved from M=3.0 in the pre-professional learning questionnaire, to M=5.0 in the post-implementation learning questionnaire, a significant result, t(26)= 7.285, p=0.001. Although teachers' perceptions of importance for students to acquire maker learning capabilities increased from M=5.0 to M =5.37, this gain was not significant – nor was the increase in enthusiasm to teach in makerspaces from M=5.22 to M=5.56. However, the upward trend and generally high levels (between 'agree' and 'strongly agree') are noted. The project did result in a shift in teacher identity, with participants identifying as a 'maker' significantly more in the post-final questionnaire (M=5.0) than in the pre-questionnaire (M=4.1), t(26)=4.22, p=0.001. The project also resulted in a significant increase in teachers' general confidence to teach with technology, t(26)=5.2, p=0.001. Qualitative responses to the questionnaire confirmed themes arising in the teacher reflective journals and focus group interviews.*

## 11.1 About the Teacher Post-Implementation Questionnaire

This chapter reports on the analysis of the final project evaluation (referred to as "post-implementation") questionnaire, issued to participants on November 22nd, 2017. All 27 project participants completed the post-implementation questionnaire. The complete instrument can be found in Appendix 6. The section includes both discrete analysis of the post-implementation data, as well as a combined analysis the data with the other two questionnaires in the project – specifically, the pre- and post-professional learning questionnaires.

## 11.2 Post-Implementation Questionnaire: Quantitative Analysis

Whole-group frequency counts were performed for five rating items, followed by school group comparisons for these items. Cross-analysis was then conducted between responses to these items, and responses to questions in the pre- and post-professional learning questionnaire. The pre-questionnaire variables of *Confidence with Technology*, *Years Teaching, Age (5- and 10-Year Increments)* and *Rating Items* were all used to compare means between groups.

## 11.3 General Confidence with Technology: Pre- and Post-Implementation Levels

As with the pre-professional learning questionnaire, a single item using a fully-anchored five-point scale ranging from (0) "Very Low" to (4) "Very High" was included to measure general confidence with technology (*How would you rate your confidence in teaching with technology?*). Given the uniformity in wording and focus of both items, a paired-sample T-test was employed to explore whether mean differences between the two measures were significant. The T-test revealed that, on average, participants reported significantly greater general confidence teaching with technology in the post-implementation questionnaire (M=2.44, SD= .64) than in the pre-questionnaire (M=1.81, SD=.79), $t(26)=5.2$, $p=.001$. Figure 11.1 illustrates this shift.

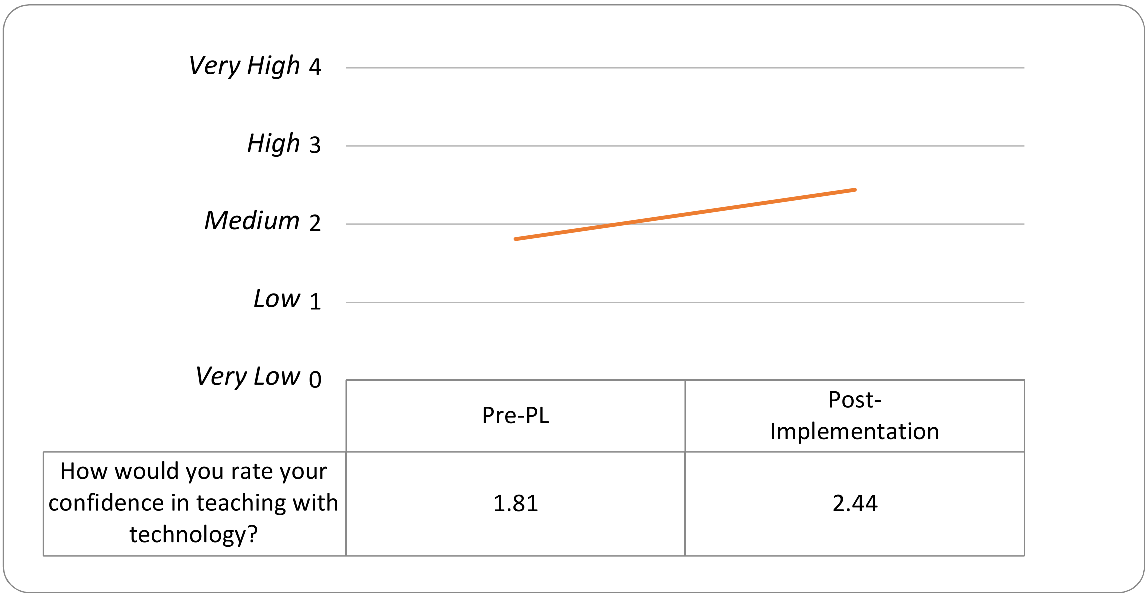



Figure 11.1 – Confidence teaching with technology (pre-professional learning and post-implementation)

## 11.4 Post-implementation Likert Scale Items

Four other items were included in the post-implementation questionnaire that precisely matched the wording and focus of items in the pre-questionnaire, employing the same 7-point fully-anchored scale ranging from (0) “Strongly Disagree” to (6) “Strongly Agree”, with (3) being “Neither Agree nor Disagree”:

1. It is important for students to acquire maker learning capabilities;
2. I see myself as a ‘maker‘;
3. I feel confident to teach in makerspaces; and
4. I feel enthusiastic about teaching in makerspaces.

Table 11.1 summarises the mean scores for the four 7-point items in the post-implementation questionnaire. Of note, scores for all items were high, falling in the range of 5-6 (“Agree” and “Strongly Agree”).

Table 11.1 – Items Rated (All Schools)

| | It is important for students to acquire maker learning capabilities | I see myself as a ‘maker‘ | I feel confident to teach in makerspaces | I feel enthusiastic about teaching in makerspaces |
|---|---|---|---|---|
| *Mean* | 5.37 | 5.00 | 5.00 | 5.56 |
| *Std. Deviation* | .742 | .832 | .620 | .577 |

Comparisons of means for these items by *School*, *Age* and *Years Teaching* did not show significant differences. For *Edmodo Participation*, one item (“It is important for students to acquire maker learning capabilities”) showed significance, with Edmodo participants reporting significantly higher levels of agreement (M=5.73, SD=.47) than non-participants (M=5.13, SD=.81), $t(25)=-2.23$, $p=0.034$.

## 11.5 Items Rated: Pre-Professional Learning and Post-Implementation Levels Compared

Given the use of the common 7-point scale and four items, mean responses to each of the items were compared between pre-professional learning and post-implementation questionnaires. All the items showed noticeable differences in means, prompting the application of paired-samples T-test to test for significant differences. The results of the T-tests are shown in Table 11.2. Of note, all four items showed an increase in mean, with three of the four mean differences being significant. In particular, teachers in the post-implementation questionnaire reported significantly higher levels of confidence (Item 3) teaching in makerspaces (M=5.0, SD=.62) than in the pre-professional learning questionnaire (M=3.04, SD=1.16), $t(26)=7.29$, $p=0.000$. Participants similarly reported identifying “as a maker” (Item 2) significantly more in the post-implementation questionnaire (M=5, SD=.73) than in the pre-professional learning questionnaire (M=4.07, SD=1.07), $t(26)=4.22$, $p=0.000$. Finally, participants reported being significantly more enthusiastic (Item 4) in the post-implementation questionnaire (M=5.56, SD=.58) than was the case in the pre-questionnaire (M=5.22, SD=.75), $t(26)=2.55$, $p=0.017$.

Table 11.2 – Paired-Samples T-Test: Pre-Professional Learning and Post-Implementation Rating Items

| | Pre-Professional Learning Questionnaire | | Post-Implementation Questionnaire | | t | df | Sig (2-tailed) |
|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | | | |
| *1. It is important for students to acquire maker learning capabilities* | 5.0 | .73 | 5.37 | .74 | 1.91 | 26 | .067 |
| *2. I feel confident to teach in makerspaces* | 3.04 | 1.16 | 5.0 | .62 | 7.285 | 26 | .000 |
| *3. I feel enthusiastic about teaching in makerspaces* | 5.22 | .75 | 5.56 | .58 | 2.55 | 26 | .017 |
| *4. I see myself as a 'maker'* | 4.07 | 1.07 | 5.0 | .83 | 4.22 | 26 | .000 |

To explore whether differences of mean for confidence and enthusiasm were statistically significant across all three stages of the project, a repeated measures ANOVA was performed for each construct. When examining makerspaces confidence, Mauchly's test indicated that the assumption of sphericity had been violated, $\chi2(2) = 19.97$, $p < 0.05$, therefore multivariate tests were reported ($\varepsilon = .65$). The results showed that levels of confidence were significantly affected by the stage of the study, $V = 0.73$, $F(2, 25) = 33.33$, $p = 0.001$. Similarly, Mauchly's test for enthusiasm indicated sphericity violation, $\chi2(2) = 12.86$, $p < 0.05$, $\varepsilon = .71$, showing that levels of enthusiasm were also affected by the stage of study, $V = 0.36$, $F(2, 25) = 6.94$, $p = 0.004$. Post-hoc comparisons using T tests with Bonferroni correction showed that the mean score for post-professional learning confidence (M=4.4, SD=0.8) was significantly different to the pre-professional learning score (M=3.04, SD=1.16), and that the post-implementation confidence score (M=5, SD=0.62) was significantly different to the post-professional learning score. Post-hoc comparisons using the same tests showed that the mean score for post-professional learning enthusiasm (M=4.78, SD=1.16) was not significantly different to the pre-professional learning score (M=5.22, SD=0.75), although the post-implementation score (M=5.56, SD=0.58) was significantly different to both post-professional learning and pre-professional learning scores.

To explore the post-implementation *Rating Items* in relation to the 5-point item for general confidence teaching with technology (*How would you rate your confidence in teaching with technology?*) common to both pre- and post-implementation questionnaires, three clusters – "Low and Very Low" (1-2), "Medium" (3) and "High and Very High" (4-5) – were computed for the post-implementation response similar to the three clusters computed in the pre-questionnaire. Table 11.3 shows the differences of mean between these clusters. Given that in the post-implementation questionnaire, only one teacher reported "Low and Very Low" confidence, the differences lie between the "Medium" and "High and Very High" clusters, where the "Medium" group reports higher mean scores for Items 1 and 4. The same post-implementation items were then checked against the pre-questionnaire general confidence clusters to observe any noticeable differences in mean. Like the results shown in Table 11.3, there were only nuanced differences between the three groups.

Table 11.3 – Items by Post-Implementation Questionnaire Confidence Clusters

| *Post-Implementation Confidence with Technology (3 Clusters)* | | It is important for students to acquire maker learning capabilities | I see myself as a 'maker' | I feel confident to teach in makerspaces | I feel enthusiastic about teaching in makerspaces |
|---|---|---|---|---|---|
| *Low or Very Low (n=1)* | Mean | 5.00 | 5.00 | 4.00 | 5.00 |
| | Std. Deviation | . | . | . | . |
| *Medium (n=14)* | Mean | 5.57 | 5.00 | 5.00 | 5.71 |
| | Std. Deviation | .514 | .877 | .555 | .469 |
| *High or Very High (n=12)* | Mean | 5.17 | 5.00 | 5.08 | 5.42 |
| | Std. Deviation | .937 | .853 | .669 | .669 |
| *Total (n=27)* | Mean | 5.37 | 5.00 | 5.00 | 5.56 |
| | Std. Deviation | .742 | .832 | .620 | .577 |

## 11.6 Post-Implementation Questionnaire: Qualitative Analysis

The post-implementation questionnaire included six open questions that directly mirrored those asked in the pre-professional learning questionnaire. Question 1 explored teachers' understanding of makerspaces at the time of survey, while Questions 2-3 invited them to share benefits and issues they derived from teaching their units of work. Question 4 explored support and pedagogical strategies in general, whereas Question 5 personalised the theme of support by asking teachers to identify what they most needed for their maker classes to be successful:

1. To you, what are makerspaces?
2. What benefits do you feel students have acquired from undertaking maker activities? What do you feel they have learnt?
3. What issues did you encounter when teaching in makerspaces? What constrained student learning in maker activities?
4. What do you think supports learning in maker activities? What pedagogical strategies can you suggest for teaching in makerspaces?
5. What support/s do you feel are the main things you need in order for your maker classes to be as successful as possible?
6. Please add any other thoughts or suggestions in the space below.

Due to the similarity of questioning to that used in both the pre-professional learning questionnaire and post-implementation questionnaire, the research team chose to iteratively build on the category system that was used for the earlier questionnaire. The same themes of *Makerspaces as…, Enterprise Skills, Socio Behavioural (Learning Behaviours), Teacher Efficacy* and *External School Factors* were broadly evident in the data, largely due to the overlap of questioning across the three questionnaires.

Table 11.4 shows the category system used across the three datasets. Except for the "knowledge of makerspaces", which was not referenced in the post-implementation data as an explicitly-stated outcome, all other second-order themes were referenced and retained. There were a small number of additional themes that teachers identified in their responses. These themes were mainly related to the perceived benefits to makerspaces, and included resilience, communication skills, content knowledge, and design thinking. Given the in-depth treatment of these themes elsewhere in the report, the research team chose not to create any further themes to preserve consistency and allow for better qualitative comparison across the three questionnaires.

Table 11.4 – Coding Structure Employed in NVivo – Pre-, Post- and Final- Questionnaires

| | **Pre-Professional Learning Questionnaire** | | **Post-Project Questionnaire** | |
|---|---|---|---|---|
| *Code:* | No. Coding Refs | No. Words Coded | No. Coding Refs | No. Words Coded |
| *Makerspaces as...\Curriculum* | 3 | 48 | 4 | 156 |
| *Makerspaces as...\Opportunity-means* | 5 | 51 | 8 | 268 |
| *Makerspaces as...\Pedagogy* | 12 | 157 | 11 | 263 |
| *Makerspaces as...\Places-spaces* | 6 | 54 | 21 | 576 |
| *Makerspaces as...\Technology* | 7 | 42 | 2 | 60 |
| *2. Enterprise Skills* | 37 | 416 | 50 | 1,860 |
| *Skills\Creativity* | 15 | 164 | 15 | 502 |
| *Skills\Critical Thinking* | 4 | 32 | 17 | 679 |
| *Skills\Inquiry* | 3 | 39 | 8 | 244 |
| *Skills\Problem Solving* | 15 | 181 | 10 | 435 |
| *3. Socio-behavioural (learning behaviours)* | 19 | 180 | 25 | 911 |
| *Socio-behavioural\Collaboration* | 10 | 88 | 11 | 368 |
| *Socio-behavioural \Engagement* | 3 | 21 | 5 | 232 |
| *Socio-behavioural \Enthusiasm* | 1 | 8 | 2 | 50 |
| */Socio-behavioural \Risk taking* | 5 | 63 | 6 | 219 |
| *4. Teacher Efficacy* | 29 | 290 | 34 | 1,290 |
| *Teacher Efficacy\Attitudes* | 2 | 13 | 3 | 102 |
| *Teacher Efficacy\Best form of PL* | 0 | 0 | 1 | 6 |
| *Teacher Efficacy\Best pedagogies to employ* | 7 | 116 | 19 | 579 |
| *Teacher Efficacy\Confidence with technology* | 13 | 111 | 7 | 274 |
| *Teacher Efficacy\Planning* | 0 | 0 | 5 | 31 |
| *Teacher Efficacy\Support for learners* | 2 | 17 | 10 | 466 |
| *Teacher Efficacy\Knowledge of makerspaces* | 5 | 33 | 0 | 0 |
| *5.External School Factors* | 60 | 521 | 65 | 1,633 |
| *External School Factors\Collegial Support* | 24 | 206 | 14 | 342 |
| *Ext. School Factors \Problems with tech* | 13 | 160 | 21 | 514 |
| *External School Factors\Resources* | 11 | 83 | 24 | 585 |
| *Teacher Efficacy\Opportunities to Plan* | 0 | 0 | 1 | 15 |
| *External School Factors\Time* | 12 | 72 | 5 | 177 |

## 11.7 Theme 1: *Makerspaces as…* and the Evolution of Teachers' Thinking

Like previous analyses, Question 1 ("To you, what are makerspaces?") informed the coding for this theme. The most commonly-referenced theme was "makerspaces as places-spaces" followed by "makerspaces as a pedagogy", suggesting that teachers primarily view makerspaces as a space that encourages less traditional and more innovative pedagogical approaches. This represented a slight shift from the findings in the pre-professional learning questionnaire, where teachers mainly referred to pedagogy and 3D printing in their conceptions of what makerspaces were and what they enabled. For the post-implementation responses, all teachers (100%) in the sample were able to reference at least one definition of makerspaces from their point of view.

Perhaps the most significant contrast between pre-professional learning and post-implementation responses was the emphasis on makerspaces as places and/or spaces. Among the 18 teachers (66.7%) describing makerspaces in the post-implementation responses, there were strong references to the impact that a well-designed makerspace can have on learning. Many teachers, such as Amanda, Ella and Andrea stressed the importance of the space being flexible – in Ella's words, "creative, open-ended design spaces for solving real life problems". Other teachers emphasised the applicability of the space to the design process. For example, Madalyn viewed makerspaces as "spaces for students to put their design thinking into action, where they can collaborate, investigate, design, make, test, evaluate and redesign and reflect", whereas Emma suggested they represent "are a space where students are able to use a variety of tools to experiment with design in order to solve a real life problem... a space where students design, tests and redesign in order to create effective products". A third group of teachers suggested that makerspaces were triggers for implementing new pedagogical approaches. As Samantha explained, "makerspaces are engaging learning areas where students can creatively investigate something... they are able to use skills of inquiry, technology and tools to design and make certain projects". Corinne simply described makerspaces as "creative spaces, where children lead the learning". These responses suggested that teachers had – at the end of the study – a more grounded understanding of how space informing the makerspace impacts on learning. Since all teachers had configured their classroom as makerspace, they were able to concretely evaluate the efficacy of the space they had configured.

Like the pre-professional learning questionnaire – where ten teachers (37%) referred to makerspaces as a form of pedagogy – 11 teachers (40.1%) referenced them in this way in the post-implementation responses. Interestingly, similar pedagogies were explored in the two datasets, though the post-implementation stage seemed to reflect a shift from potential pedagogies to actualised ones through the teaching and learning implementation. Nadia saw "challenge-based tasks" as defining feature of makerspaces, while Molly described makerspaces as mainly involving "hands-on problem solving and designing". Several teachers – including Tim, Jasmine, and Dawn – identified Project-Based Learning (PBL) as the defining feature. Other teachers, such as Sophie, Madalyn and Ella viewed makerspaces as a form of authentic learning, with Sophie explaining they are "creative, open-ended lessons that allow students to explore possible solutions to either a real problem or a creative challenge using technology". Alice believed that makerspaces represent a synthesis of pedagogies that support and enhance learners:

> Makerspaces is [sic] bringing the best pedagogies together, delivering the ultimate teaching and learning experiences for students and teachers. It [is about] problem solving, thinking critically and creatively and integrating across all KLAs. It's empowering students to propose solutions, try and refine without the fear of failure. It's the best example I have seen of collaboration between students (and teachers!) It really is bringing learning to life.

Further, in the post-implementation responses, there appeared to be fewer brief references to approaches and models, and more descriptive references to what the learning looks like because of the pedagogies used. Like their understanding of space, this suggested that teachers had a more grounded understanding of how to employ maker pedagogies to maximise learning outcomes and support their students through the design process.

Both pre-professional learning and post-implementation questionnaires only prompted a small number of teachers refer to makerspaces as curriculum. However, in the post-implementation responses, the four teachers (14.8%) referencing makerspaces as a form of curriculum highlighted the importance of learning across the curriculum as a factor determining success with makerspaces. Rachel stressed that "opportunities for persistence and critical thinking need to be integrated across the curriculum so that students can successfully and effectively design, create and reflect...and become self-regulated learners". Madalyn felt that "conceptual planning can draw on multiple KLA outcomes to create a broader unit that draws more on what students already know and have learned". Hannah felt that students should be given "ample opportunities across all Key Learning Areas through STEM. Evaluation and reflecting on tasks independently and as a group", whereas Dawn underscored the importance of a "strong understanding of curriculum and being able to adapt it to any KLA". These responses seemed to suggest that teachers had become convinced that makerspaces could support curriculum integration, and perhaps that the earlier fears of finding time to implement makerspaces in a "crowded curriculum" were less of a concern. Furthermore, teachers at this stage of the study had essentially enacted the curriculum through their implementation.

In contrast to the pre-professional learning responses, one fifth of the sample (n=6, 22.2%), saw makerspaces mainly an opportunity or means for improved learning outcomes. Alluding to sustainability, Rachel felt that they were "opportunities for the students to utilise the resources available to them (including recycled materials) to design and create for different purposes". Jane saw makerspaces as a rare opportunity for students to "design something to find a solution to a problem", while Julia viewed them as an "opportunity to design, create and problem solve using a variety of mediums including digital technology". Diana saw makerspaces as an opportunity for developing critical and creative thinking in "a structured and unstructured learning environment and also an area in which students can gain many skills such a team work, communication, collaboration, evaluation, and persistence". Drawing attention to makerspaces as an opportunity to rethink the spaces that teachers already have, Ella broadly defined makerspaces as "anywhere that students are being creative, designing, making, evaluating and refining". Though small in number, these responses suggest that teachers had a more nuanced understanding of the opportunities presented by the introduction of makerspaces in their context.

In contrast to six teachers (22.2%) in the pre-professional learning questionnaire, only two teachers (7.4%) referenced makerspaces as a form of technology at this stage of the study. Dawn regarded makerspaces as way to develop higher order thinking, problem solving and critical thinking through the *Makers Empire 3D* app, whereas Abigail saw makerspaces as a vehicle for developing a wide range of technology skills, "especially when using iPads". This represents a curious shift, perhaps pointing to a belief that makerspaces cannot be reduced to technology alone, or that technology is a tool for supporting maker learning, rather than an end in itself.

## 11.8 Theme 2: 21st century skills and the Evolution of Teachers' Thinking

Collectively, 17 teachers (63%) referenced the four 21st century skills that were earlier identified and discussed in the pre- and post-professional learning questionnaires. Question 2 ("What benefits do you feel students have acquired from undertaking maker activities?") was of primary relevance when exploring this theme, although some teachers identified these skills as supporting elements for successful makerspaces in response to either Question 4 ("What do you think supports learning in maker activities?") or Question 5 ("What support/s do you feel are the main things you need…?"). Broadly speaking, the emphasis on these skills in the post-implementation responses was consistent to their emphasis in the pre-professional learning responses.

Among teachers' references to the 21st century skills at this stage of the study, critical thinking received the most attention, with 17 teachers (63%) identifying its importance in relation to makerspaces. For Penny, Emma and Alice, critical thinking appeared to be closely related to the refinement of designs. Penny described this as students "looking critically at their work and refining it", and Emma noted that her students could now "critically reflect on their designs and test whether it creates the effect that they wanted". Alice referred to students' capacity "to try and refine without the fear of failure". For others such as Rachel and Samantha, critical thinking was linked to better questioning in the classroom. As Rachel explained, "students are asking more specific questions… and [are] more able to explain their opinions and ideas". Samantha believed that her students were now "more confident to question methods and ways to go about something". Others, such as Jenna, saw critical thinking as connected to authentic learning and inquiry: "I think my students have been able to explore what it is like to learn in a future focused setting… they're able to investigate real world problems independently and explore their critical thinking skills and designing skills. Referring to one of the underlying objectives of constructionism, Amanda believed that she could "see such positive changes in my students, and they are so excited to learn and experience 'hard fun'". Perhaps the most significant indicator of the evolution of teachers' thinking here was their tendency to provide clear examples of the skills in their classroom context. Critically, the language had shifted from qualifications like "hopefully" and "will" to "have been", "are" and "did".

Thirteen teachers (48.1%) referred to creativity in their responses. For the most part, teachers in this group believed that their students' creativity had improved because of learning in makerspaces and simple references to "greater creativity" were the most common form of response. However, some teachers discussed how creativity related to other attributes, such as Nadia, who saw it interlinked with flexibility, finding "greater creativity in my students and flexibility when they are faced with a challenge". Hannah saw a connection between creativity and the use of both physical and non-physical materials, referring to "creativity [and] exploration using concrete materials, writing, drawing and technology". Emma felt that the shadow puppet task "was a very creative and challenging task that integrated many facets of learning, such as technology, Science and literacy". Kim similarly felt that her class narrative task "allowed the students to show their creative side and to investigate situations to improve on… a different side to express their thoughts and ideas".

Problem-solving was an area of focus for a third of the participating teachers (n=9, 33.3%). Again, most teachers in the group simply referenced improvements to problem solving without going into further detail. For Rachel and Julia, however, problem solving, creativity, and authenticity went together. Rachel's students had "learnt that problem solving is a part of their everyday living, and that while they can suggest multiple solutions and ideas to solve problems, the process of modifying and finding the best solutions and evaluating their choices is most important and will thus become skills that will ensure their success in life". Julia's students had shifted "in thinking from 'I've done the task and I am finished' to 'I think I will keep working and try it another way". She also referred to improvements to "the metalanguage of problem solving", observing that "we now reflect more on the things we can't do, and what we can do to move forward". Molly's students engaged in problem solving through "active discussion", whereas Penny's students problem-solved by "working to a set criteria, [engaging in] self-evaluation, looking critically at their work, and refining it". These enacted forms of problem solving represented a development from the pre-professional learning responses, which emphasised "big questions" and "real world problems" but did not provide clear accounts of how the problem solving should, or could, occur.

By contrast to the two teachers (7.4%) in the pre-professional learning data who simply named "inquiry" as an attribute of makerspaces, five teachers (18.5%) now described how inquiry was an integral part of teaching and learning in their makerspaces. Rachel believed her students were "asking more specific questions", while Jenna's students were now "able to investigate real world problems independently". Samantha referred to students who had "gained skills in their inquiry process… and are able to use these skills with technology to design projects", adding that "a culture of inquiry supported these lessons greatly". Hannah saw "exploration" as a key supporting element for effective learning in makerspaces. Andrea believed that "teachers have stepped back, and students are leading the learning and inquiring".

## 11.9 Theme 3: Learning Behaviours and Evolution of Teachers' Thinking

Similar cohorts of teachers referred to learning behaviours in the pre-professional learning data (n=16,59.3%) and post-implementation data (n=17, 63%). Like the pre-professional learning questionnaire, the number of references in the post-implementation data for each theme was relatively low. However, collaboration was an area that ten teachers (37%) note in their responses. For Rachel, Penny, Molly, Ella, and Kirsten, collaboration and peer feedback appeared well-connected. As Rachel explained in relation to her class, "students are learning from their peers and interacting positively", adding that "students who may not necessarily be high achievers academically thrive in these opportunities and experience success". Penny's students seemed to be particularly good at "helping each other with the app and ideas at their makers table… sharing resources, taking turns, and peer-reviewing work". Molly's students were particularly good at "team work", while Ella's students had become good at "taking and giving constructive feedback". Kirsten's students had similarly "learned how to work together and become much better at providing constructive feedback to their peers". Abigail's students now worked well in groups, while Andrea noted that both "collaboration and communication skills have improved". Like the skills discussed in the previous section, the data for collaboration now points to grounded references to successful and genuine collaboration in the teachers' classrooms.

Six teachers (22.2%) explicitly referenced engagement in their responses, and all teachers in this category viewed their learners as very engaged while learning in makerspaces. Tim described the level of engagement in his class as "high", while Rachel concluded that "the children were engaged, I was inspired and together, we learned so much". Madalyn felt the unit was an achievement in terms of engaging students in STEM learning, "which is very important in terms of future-focused pedagogy". Dawn pointed out that the *Makers Empire 3D* app was "highly engaging". Diana believed that "all of my students were highly engaged during the entire program and were always asking when their next [makerspaces] lesson would be" Mackenzie observed that some of her class leaders "gained confidence and skills in engaging younger students [peers]". Sally's students were "focused and motivated". When viewed in contrast to the brief references to engagement in the pre-professional learning data, these findings suggested that engagement in makerspaces had become much more than simply “staying on task”.

Only three teachers (12%) specifically cited enthusiasm in their responses. However, the evolution in teachers’ thinking suggested that they now saw enthusiasm as means, rather than end. For example, Tim felt that his students were all very enthusiastic, leading to him feeling “more confident and enthusiastic about teaching makerspaces next year”. Jane believed that her children were also very enthusiastic, leading to “parents who were positive and seemed impressed”. Amanda’s believed that she had seen a positive change in her students, who are very excited in the way they responded to challenges.

The same number of teachers (n=5, 18.5%) referred to risk taking in pre-professional learning and post-implementation responses. Again, though, the post-implementation findings pointed to actual examples of students taking risks in the teachers’ classrooms, and the effect this had on learning. Rachel’s students were more confident taking risks than previously, and as a result, “less afraid to make mistakes”. Samantha believed that she had reached her students “by modelling risk taking, so they feel more confident in taking risks in their designs”. Sally believed that her students were now willing to “fail, but not giving up” when faced with challenges, while Andrea felt that students had “learned to be risk-takers, to fail well and try again”. Amanda drew attention to students who were now less risk-averse in the way they approached new learning experiences: “my students are more confident when attempting new activities ... They are less upset when they fail and see it as a more positive step in the design process as they know they will be given time to change and improve their design. They are more confident risk-takers because of this”.

## 11.10 Theme 4: Teacher Efficacy and the Evolution of Teachers’ Thinking

Like Theme 3, teacher efficacy was a theme referenced across all questions, and the research team looked for specific first-person references about the teacher and their experiences teaching in makerspaces. The theme “best pedagogies to employ” was the most widely-referenced second-order theme in this category, while at the other end of the scale, one theme, “knowledge about makerspaces” was not referenced at all in the data.

In the post-implementation responses, 16 teachers (59.3%) articulated pedagogies they feel are best suited to teaching in makerspaces. This stands in contrast to the six participants (22.2%) who mainly questioned which pedagogies they should employ in their future makerspace. The post implementation findings point to a belief in the value of pedagogies that are learner-led, constructivist and inquiry-oriented. At the same time, many teachers tempered their responses with balanced emphasis on teacher-centred pedagogies such as explicit instruction and modelling. Tim favoured “real life problem- and project-based [forms of] learning”, while Madalyn advocated “inquiry-based learning… giving them a real-world problem and having them design a solution for that problem”. Diana believed that Project-Based Learning (PBL) had resulted in “creative thinking, and all of the fantastic designs that came from the students, not me!”. Ella liked “hand on learning experiences… with modelled examples, peer to peer feedback and support”, while Amber liked her and her students “exploring together”. Alice felt that inquiry-based learning should be key. She agreed that “there are still opportunities for explicit teaching within maker activities” but believed that “many of these opportunities arise as incidentals on the way to solving a problem”. Emma similarly believed in “a combination of explicit teaching and constructivism”, while Nadia liked a balance between “open mind and independence” and “explicit and modelled instruction linked to problem solving”. The post-implementation findings thus pointed to stronger teacher efficacy in relation maker pedagogies, perhaps simply because teachers had the opportunity to trial, develop, evaluate and improve their pedagogies throughout the teaching and learning implementation.

The second most commonly-referenced theme in relation to teacher efficacy, support for learners was an explicit area of concern and/or area of opportunity for a third of the teachers in the sample (n=9, 33.3%). This represented a sizeable increase in focus from the two brief references to this theme in the pre-professional learning data. For teachers such as Nadia, Madalyn, Emma and Kim, concerns seemed to be at the forefront of their interest in supporting learners. Nadia was worried about "not being able to address students' problems immediately", adding that when they were using the *Makers Empire 3D* app, "students could not complete tasks independently as instructions had to be read to them and they were unable to distinguish between the features on their own". Madalyn was simply worried that with the team-teaching arrangement with two other colleagues, "there were too many students in one space". Emma found it difficult to support learners with "relevant background knowledge prior to giving them access to makerspaces… [and] discovered that students needed greater exposure to concepts… before they could effectively create a design". Kim was worried that some of her "lower [ability] students struggled to understand ratios and dimensions when creating their designs". Other teachers felt that the necessary support was able to be provided. Hannah was pleased that she could consistently apply "learning intentions" to keep her students supported and on-task. Samantha used "explicit instruction, the first time, to ensure students (especially Kindergarten) knew the appropriate way to discuss if something was successful or not, how to kindly assist other students in improving their designs". Moving forward, Mackenzie felt that she should "explicitly teach collaborative skills and have prior opportunities to work in groups". The post-implementation responses thus suggested that teachers were far more aware of the challenges they faced supporting all learners during maker activities.

As noted earlier, the post-implementation quantitative data showed teachers' increased confidence to teach in makerspaces at this stage of the study. Thus, it was unsurprising to see confidence with technology receive fewer mentions as an area of concern in the qualitative data. By contrast to the 13 teachers (48.1%) mainly questioning their confidence in the pre-professional learning data, relatively few teachers (n=7, 25.9%) referred to their confidence in response to the open questions here. However, some teachers in the group still expressed reticence in terms of their confidence with technology. For example, Kirsten described the *Makers Empire 3D* app features as "quite difficult to use, even for me!", while Sally believed that her "ability to use the app" remained a success factor to be addressed in future. However, other technology-reluctant teachers like Mackenzie felt that they were, in her words "keen to have another go!". Tim was much more confident and felt that he would carry this to the next makerspaces opportunity he had. Alice was now confident to the extent that she couldn't "wait to roll this out across K-6 next year". Madalyn's improved confidence meant that she now wanted to "to do more and grow my skills as a 21$^{st}$ century facilitator".

While not receiving much attention in the post-implementation data, attitudes were still important for three teachers (11%), whereas the best form of professional learning to employ was referred to by one teacher (3.7%). Nadia now felt that open-mindedness was essential for her success with makerspaces, while Samantha now found great insight in showing her students that "I too was learning how to design and test the same object helped them know it's ok not to know and learn along the way". Andrea felt that she had seen a shift across the teaching staff involved in the project at her school, with teachers "willing to learn alongside students, teachers willing to take risks with technology themselves, and teachers programming in a different way". In terms of the best professional learning to employ, Cathie believed in "open discussion and mentoring" her staff, adding, "team teaching can provide extra support to ensure all the benefit from the experience".

## 11.11 Theme 5: External School Factors and the Evolution of Teachers' Thinking

The post-implementation findings for Theme 5 suggested that external school factors remained an area of concern for most teachers in the study, with almost all the participating teachers (n=26, 96.3%) commenting on one or more of the second-order themes included in this category at this stage. Teachers often referenced external school factors in response to Question 3 ("What issues did you encounter when teaching in makerspaces? What constrained student learning in maker activities?"), Question 4 ("What do you think supports learning in maker activities? What pedagogical strategies can you suggest for teaching in makerspaces?"), and Question 5 ("What support/s do you feel are the main things you need in order for your maker classes to be as successful as possible?"). Worryingly, the post-implementation findings often simply echoed pre-professional learning findings, suggesting that many issues had gone unresolved, smouldering in the background and occasionally negatively impacting on learning during the implementation of the makerspaces units of work.

Like the pre-professional learning data, both "problems with technology in the school" and "resources" draw the largest number of references in the post-implementation responses, with 17 teachers (63%) commenting on each. In terms of the identified technology problems, internet connectivity, access to Wi-Fi and malfunctioning iPads remained key concerns, followed by complaints about the 3D printers. For Madalyn, Tim, Mackenzie, Jane, Molly and Hannah, poor connectivity had an impact learning in their classroom. For example, Madalyn cited "weak Wi-Fi signals that constantly dropped out, making it difficult to connect to the *Makers Empire* portal", while Mackenzie stated that connectivity issues "were most frustrating for students and teachers alike". For others, such as Jenna, at times the "the app would not work", and for Amber, the app "needed to be updated" to function properly, but the update was not supported on the specific iPads used. Problematic 3D printing was an area of focus for Sophie, Jasmine, Abigail, and Amanda. Sophie explained that "extensive printer problems hindered the design and test phase as we were unable to print student designs", adding, "this problem was resolved by printing to other printers, but much time was spent trying to rectify the printing problems and it impacted the flow and timing of the project". Jasmine simply pointed out that her "printer was not working, which delayed the learning process", while Abigail stressed that "big difficulties we faced were the technology and printer problems that stopped us from being able to print the designs that students made, making it harder to use the shadow puppets in their shadow puppet shows". Amanda pointed out that a shared printer meant that the process took "a long time to print and makes it harder for the whole class to engage".

Interestingly, while resources drew only a few brief references in the pre-professional learning data (n=8, 29.6%), resources were much more widely referenced (n=17, 63%) and more fully explained as a second-order theme at this stage of the study. Resources appeared quite closely related to problems with technology in the school, with many regarding insufficient technology as a problem. The resourcing issue most clearly identified was the perceived lack of iPads, and teachers pointed out that working with a small number of shared iPads in the class made realising goals for their makerspace difficult. Tim, Mackenzie, Molly, Sally, Jane, Amanda, and Kim all stipulated a need for a greater number of iPads in each class. For Jane, Amanda, and Kim, the need for one iPad for every student in the classroom was evident so, in Kim's words, "all students can be involved at the same time". Aside from adequate Wi-Fi coverage expressed by Madalyn, Tim, Mackenzie, Jane, Molly, Hannah, and Nadia, other references to resources were more general, and appeared to encompass the physical materials required for offline making. Nadia said she would like “enough resources on hand to enable free making or challenge-based activities”, whereas Sally wanted greater “availability of resources”. Alice sought a “dedicated Makerspace area within the school to have all of the materials readily available, instead of wasting time packing up”, whereas Rachel sought “a designated space, with more recyclable materials to create items and technology to support”. Penny wanted a “greater variety of resources”. Julia said she would like “a budget to purchase a variety of resources for my classroom with appropriate storage that students can access when needed as part of their learning”, and Kim said she would like both “resources and teachers’ guides”. The post-implementation findings suggested that teachers now had a more detailed knowledge of specific resources that are needed to successfully implement their makerspaces moving forward.

Across both pre-professional learning and post-implementation datasets, collegial support received similar attention, with 12 teachers (44.4%) stressing its importance in their post-implementation responses. Like resourcing, all teachers in this category were unanimous in their agreement that strong collegial support was a necessary factor for their success with makerspaces, and most now presented a detailed account of what this looked like in their context. Identified collegial support was perceived in two main forms, with several teachers identifying technical support as the type of support they need, and the remainder of teachers implying that support needs to come from fellow teachers in either planning or implementation. In terms of technical support, Dawn, Sophie, Jasmine, Abigail, Andrea and Mackenzie all felt that it was necessary. Dawn underscored the need for “instant tech support” with the school’s 3D printer, while Sophie explained she needed “technical support to rectify any hardware or software problems that arise”. Abigail stated that “technological support is really important to make it [the makerspace] successful”, while Andrea said she would like technical support to follow further professional learning. For other teachers, collegial support seemed more closely tied to the colleagues in the school. As Emma explained, “strong collegial support was also important, as I often consulted with my colleagues on how the designs were working and the process through which they were teaching the skills needed for students to design their products”. In addition to requesting “ongoing professional development, [and] a bank of lesson and program ideas”, Diana sought “support from other teachers, for example, through team teaching”. Alluding to the need for further support from a broader base, Ella conceded, “in hindsight, I would have used support staff and parent helpers”.

In contrast to the pre-professional learning data, time was a concern only shared by five teachers (14.8%). There was now apparent consensus that further available time would increase their success with makerspaces. Samantha explained that her class needed more time than was initially thought for the opening stage of the unit of work:

> It required a significant amount of explicit instruction the first time to ensure students (especially Kindergarten) knew the appropriate way to discuss if something was successful or not, how to kindly assist other students in improving their designs. Students required encouragement in risk taking, especially when designing and testing objects and it took a while for them to feel comfortable knowing something might not work, but we can learn from it.

Abigail echoed this finding, stating, “I believe that the [teacher’s] ability to let students have the time and space to design is extremely important. It is really important to let students have the ability to choose and design, and later on reflect on their ideas”. Drawing attention to the pressures of Term 4, Diana pointed out that “time is of the essence, especially at this time of year”. Ella simply believed that further time was essential for improving on current success. Alice referred to both time and the opportunity for further planning, suggesting an important link between these two areas when she stated her need for "time to develop new Science units that incorporate maker activities".

## 11.12 Limitations of the Post-Implementation Questionnaire

The aim of the post-implementation questionnaire was, at the very end of the study, to capture teachers' perceptions about the project as a whole. Quantitative analysis remained limited by the small sample size and range of procedures that could be applied when working with the data. Occurring at the end of a busy school term, teachers' responses to the open questions were generally brief, to some extent limiting the inferences that could be drawn. The use of the same questions as those in the pre-professional learning questionnaire enabled the same category system to be used; however, this also meant that responses did not always show substantial development or variation when compared with earlier responses – as was the case, for example, with the persistent technology challenges noted across both sets of responses. Asking additional questions such as "How did you address the technology challenges you identified earlier?" or similar may have helped to more fully reveal the evolution of teachers' thinking in certain areas. Finally, the absence of questions pertaining to maker identity, maker values and general technology confidence in the post-professional learning questionnaire meant that when asked in the post-implementation questionnaire, these variables could only be compared with the responses in the pre-professional learning questionnaire.

## 11.13 Post-Implementation Questionnaire: Summary and Concluding Remarks

Despite the limitations of working with a small sample, the quantitative results clearly showed that both general confidence teaching with technology and confidence teaching in makerspaces significantly increased from the pre-questionnaire stage to the post-implementation questionnaire stage. Further supporting the earlier finding that confidence teaching with makerspaces increased when measured at the end of the professional learning program (via the post-professional learning questionnaire), the results overall suggest that the professional learning program and their experiences implementing makerspaces units of work both had positive effects on teachers' confidence. In summary, teachers feel much more confident to teach in makerspaces, and feel more confident teaching with technology in general.

The increase in teachers seeing themselves as makers was a particularly pertinent finding. Prior to their involvement in the study, it appeared that teachers were far less likely to see themselves as makers when compared with the post-implementation data. The statement "I see myself as a maker" did not necessitate teaching in makerspaces per se; it could be argued that the statement is as much about general creativity and design. Perhaps the teachers now more strongly identifying as makers were intimating their capacity to see themselves as creators, designers, and/or problem-solvers. Further research might tease out what maker identity means, and what benefits might arise from increases in one's identification as a maker.

Finally, the small but significant rise in enthusiasm suggest that teachers were now more enthusiastic than ever before, even though their levels of enthusiasm entering the study were already very high. High enthusiasm at this stage in the study – and at the end of a busy teaching year - points to success, enjoyment, interest, and a willingness to continue teaching in makerspaces in the future.

The responses to the open questions reveal significant, concluding remarks. The ideas expressed in these responses are more concrete than in the pre-professional learning questionnaire, where the same questions were used, and similar themes were explored. The post-implementation data strongly reflected the fact that the teachers had tested their ideas through design, implementation, reflection and discussion. In so doing, they had wrestled with the challenges and learned from their experiences. The coding enumeration goes some way to showing what themes were at the forefront of their minds moving forward, with five commonly-referenced themes reflecting the following:

1. makerspaces as a physical space, and the importance of maximising the space for learning;
2. the best pedagogies to employ, and how these might be refined;
3. the importance of the critical thinking skills that have been observed;
4. resourcing issues, and how they might be addressed; and
5. problems with technology, and how they might be overcome.

Other, less widely-referenced themes appeared more taken for granted. For example, far fewer teachers referenced benefits like creativity, engagement, and risk-taking. However, references to these skills were now more detailed, with clear examples usually being offered that provide evidence of improvements. Significantly, teachers were less concerned about professional learning, not at all concerned about their understanding of makerspaces, and not greatly concerned about their levels of confidence with makerspaces or maker technologies.

At this stage of the study, teachers saw makerspaces as physical spaces that can benefit learning, while recognising that the space needs to be properly set up, adequately resourced and pedagogically informed. Tied to this understanding was the issue of resources – in particular, technology resources – that chiefly included a sufficient number of up-to-date iPads, and a stable and accessible Wi-Fi network. While most teachers indicated would be happy for just having a few more iPads, some really favour having a full class set. The Wi-Fi network seemed to create an element of unpredictability, and this could frustrate teachers' efforts – in turn frustrating their students. Teachers wanted stability and reliability, so they could know the lessons could proceed as planned. However, the problems they encountered did not seem to have adversely impacted on their willingness to continue with makerspaces, and most teachers seemed to accept that technical setbacks were par for the course. Other teachers within the school stand to benefit considerably from the trial and error trouble-shooting required for success during the implementation. Most of the teachers in the sample had acquired solutions and workaround strategies to deal with the problems encountered.

The data further showed that teachers were continuing to explore their pedagogies, being sensitive to the most effective maker pedagogies. Short answers like those provided here in the questionnaire responses did not provide the richness and depth that this area deserves, but the fact that pedagogy received ample attention across the responses suggested that teachers really wanted to explore this area further. Open-ended inquiry-oriented methods appeared to take centre stage, and there was the implication that these pedagogies were new for some of the teachers. However, most teachers were keen to reinforce the value of more teacher-centre methods – in particular, explicit instruction and modelling. Teachers were also aware that these methods could take more time, so the three areas of time, pedagogy, and curriculum appeared to represent a kind of juggling act that teachers felt they needed to undertake to maximise their students' learning in makerspaces. As a result of the professional learning and makerspaces experience that they had garnered, all teachers indicated they wanted to continue to teach in makerspaces in the years to come

# 12 Teacher Focus Group Analysis

*Following the implementation of the makerspaces modules, four focus groups were conducted, involving 24 teachers. Teachers identified a range of positive learning outcomes emerging from the project including improvements to creativity, collaboration, critical thinking, problem solving, reflection, engagement, excitement, confidence, and resilience. Teachers identified some heretofore unmentioned strategies, such as explicit integration of a design thinking cycle, encouragement of constructive peer feedback, and provision of adequate time to experiment. Challenges from the implementation were also referenced, including technical problems with the 3D printing, the time it took to print objects, teachers' lack of technical knowledge, limited access to support, and time constraints inherent in their teaching of the curriculum. In addition, some kindergarten teachers felt that manipulating and interpreting the Makers Empire 3D app posed literacy and dexterity challenges for their young learners. Teachers viewed the appropriate configuration of their makerspaces as imperative, identifying equipment, flexible furniture, and technology infrastructure as pertinent elements to consider. Several teachers appreciated how learning and teaching in their makerspace enabled them to integrate the curriculum. There were repeated accounts of less confident students being transformed by the program. Several teachers recounted extensive changes to* *their practice that had occurred because of the project, describing themselves as having become more collaborative, flexible, inquiry-based and confident with technology. All 24 teachers expressed a desire to integrate 3D design-based makerspaces in their future classes.*

## 12.1 Introduction to the Teacher Focus Groups Analysis

This chapter presents the analysis of teachers' shared insights on teaching in makerspaces in the teacher focus groups that took place at the end of the project. The protocol and questions for these focus groups are discussed before explaining the inductive coding methodology used to analyse the data. A discussion is then presented of the four first-order themes that emerged during the analysis: *Outcomes, Teacher Strategies, Challenges and Opportunities,* and *Teacher Transformation*.

## 12.2 About the Teacher Focus Groups

Two researchers conducted interviews with four focus groups of approximately 6-8 teachers at the end of the project. During these interviews, the researchers ask teachers to share their experiences teaching in makerspaces, reflect on challenges and opportunities, and identify areas of improvement and future strategies. Similar to the student focus groups, these teacher interviews were semi-structured in nature. They incorporated 13 initial questions (also found in Appendix 7):

1. Please explain to what you and your students did in your makerspace module.
2. What were the best parts of the module and why?
3. What didn't work so well during the module? How come?
4. Describe how the makerspace you used supported (or not) your delivery of the module…
5. What changes would you recommend to the makerspace/s you were using? How come?
6. Do you have any evidence that suggests this affected or impacted upon the quality of students' learning?
7. How would you describe student motivation and engagement during the activities compared to your usual classes? To what did you attribute this difference? What indicators support this judgement?
8. Did you notice any difference in students' self-confidence and self-esteem as a result of the module? What indicators support this judgement?
9. What did students learn when undertaking maker activities and how do you know?
10. What were the main things you learnt as a result of running the maker module? This can relate to teaching in makerspaces, teaching with technology, or teaching more generally.
11. Did you notice any changes in your attitudes or approaches towards teaching? If so, what were they?
12. What aspects of the professional learning support were most useful to you in preparing you to run the maker module with your classes?
13. What recommendations can you make for professional learning in order to best support you to run maker modules in your classes?

Due to limited time and the logistical challenges of covering all the issues included in the 13 questions, researchers posed groups of questions and asked teachers to address any or all of the questions in the group as they responded. In the first instance, this involved grouping Questions 1-5, moving around the interview circle, and asking each teacher in the group to speak for one or two minutes on what they did in the module, the best and worst parts of teaching with makerspaces, how makerspaces supported learning in their classrooms, and what they would change to improve their makerspace. Following the initial question group and due to limited time, other question groups did not require each teacher's response, rather inviting any teachers who wished to speak on the issues included in the question group. Other question groups included Questions 6-9 (encompassing students' learning, improvements to self-confidence and other learning behaviours, and evidence to support observations) and Questions 10-13 (encompassing what teachers' experiences informed them about their practice and values, and what they might seek to do in future).

In total, 25 teachers participated in the focus group interviews, with two of these teachers participating via email responses due to being unavailable at the time of the interview. Four interviews took place, ranging in length from approximately 23 minutes to 33 minutes, with an average length of approximately 27 minutes. The 25 teachers participating included 12 Kindergarten teachers (48%), seven Year 1 teachers (28%) and five Year 2 teachers (20%) and one non-teaching teacher (4%). Although the non-teaching participant in the focus group had not implemented or reflected on their teaching in makerspaces, they had been actively involved in visiting colleagues' classrooms, team teaching, and earlier, in the professional learning program. As such, their insights were considered valuable at this stage. Table 12.1 provides general descriptive statistics for the interviews.

Table 12.1 – Teacher Focus Group Descriptive Statistics

| | **Group 1** | **Group 2** | **Group 3** | **Group 4** | **Email Responses** |
|---|---|---|---|---|---|
| *Interview Length* | 32:44 | 26:43 | 26:18 | 22:03 | N/A |
| *Number of Participants* | 8 | 3 | 7 | 5 | 2 |
| *No. Kindergarten* | 2 | 2 | 3 | 3 | 2 |
| *No. Year 1* | 2 | 1 | 3 | 1 | 0 |
| *No. Year 2* | 3 | 0 | 1 | 1 | 0 |
| *No. Non-Teaching* | 1 | 0 | 0 | 0 | 0 |

As with other qualitative data in the study, the research team explored the data inductively through segmenting, coding and the creation of category system of first- and second-order themes. Given the large number of questions and use of question groups in the focus group interviews, the inductive approach was useful for capturing the full range of issues that participants raised. As with similar interview protocols used in the study, there was considerable overlap of ideas across the questions, so both the question groups and inductive coding helped to avoid repetition and redundancy during the analysis. Using this approach, the research team was also able to enumerate all the ideas discussed in the interviews and present these ideas thematically. Table 12.2 shows the category system that emerged through inductive analysis. The research team developed four first-order themes, including: (1) *Outcomes*; (2) *Teacher Strategies*; (3) *Challenges and Opportunities*; and (4) *Teacher Transformation*. Column 2 (Number of Coding References) provides an indicator of the frequencies with which the themes occurred in the data, while Column 3 (Number of Words Coded) provides an indicator of the level of detail provided across the responses.

Table 12.2 – Coding Structure Employed in QSR NVivo (Version 11)

| ***Code*** | **No. Coding References** | **No. Words Coded** |
|---:|---:|---:|
| *Outcomes* | 135 | 9,242 |
| *Outcomes\Autonomy* | 12 | 887 |
| *Outcomes\Collaboration* | 20 | 1,342 |
| *Outcomes\Content Knowledge* | 12 | 660 |
| *Outcomes\Critical Thinking* | 13 | 991 |
| *Outcomes\Creativity* | 6 | 200 |
| *Outcomes\Engagement* | 18 | 1,318 |
| *Outcomes\Literacy* | 19 | 1,249 |
| *Outcomes\Problem Solving* | 16 | 1,245 |
| *Outcomes\Reflection* | 5 | 247 |
| *Outcomes\Resilience* | 5 | 296 |
| *Outcomes\Students' Confidence* | 15 | 1,007 |
| *Teacher Strategies* | 78 | 6,066 |
| *Teacher Strategies\Authentic Learning* | 10 | 867 |
| *Teacher Strategies\Design Thinking* | 23 | 1,889 |
| *Teacher Strategies\Explicit Teaching - Modelling* | 8 | 502 |
| *Teacher Strategies\Offline Making* | 9 | 485 |
| *Teacher Strategies\Peer Feedback* | 6 | 499 |
| *Teacher Strategies\Play* | 15 | 1,176 |
| *Teacher Strategies\Student Demonstrations* | 3 | 196 |
| *Teacher Strategies\Team Teaching* | 2 | 293 |
| *Teacher Strategies\Third Party Tools* | 2 | 159 |
| *Challenges and Opportunities* | 110 | 6,910 |
| *Challenges and Opportunities\3D Printing* | 19 | 1,222 |
| *Challenges and Opportunities\Differentiation* | 8 | 550 |
| *Challenges and Opportunities\Physical Space* | 20 | 1,292 |
| *Challenges and Opportunities\Resources* | 12 | 738 |
| *Challenges and Opportunities\The app* | 20 | 1,080 |
| *Challenges and Opportunities\Time* | 15 | 1,045 |
| *Challenges and Opportunities\Translation* | 16 | 983 |
| *Teacher Transformation* | 68 | 4,885 |
| *Teacher Transformation\Collaborative Planning* | 5 | 424 |
| *Teacher Transformation\Flexibility* | 9 | 481 |
| *Teacher Transformation\Maker Pedagogies* | 11 | 847 |
| *Teacher Transformation\Mindset* | 20 | 1,236 |
| *Teacher Transformation\Professional Learning* | 5 | 425 |
| *Teacher Transformation\Teacher Confidence* | 10 | 820 |

## 12.3 Theme 1: Teachers Discuss Perceived Outcomes

Consisting of Questions 1-5, the first question group informed 11 perceived outcomes from teaching and learning in makerspaces:

1. Please explain to what you and your students did in your makerspace module.
2. What were the best parts of the module and why?
3. What didn't work so well during the module? How come?
4. Describe how the makerspace you used supported (or not) your delivery of the module…
5. What changes would you recommend to the makerspace/s you were using? How come?

Collaboration was identified as a positive learning outcome by 11 teachers (44%), and was the most frequently referenced of the 11 outcomes in terms both of number of references and number of words coded. Teachers seemed to view collaboration as both a means and end of improved learning. Jasmine regarded it as a strong supporting element in her students' use of the *Makers Empire 3D* app. She explained that "some students did not have that much of an experience using iPads and the apps, whereas other students did… so, it was good to see that students who had more experience were, you know, guiding them and teaching them, as opposed to me giving them feedback". Emma also alluded to the impact of students' collaboration on her teaching, observing that during the unit, "little groups would come and work on it [the task] together… and I found that I was like 'Whoa – this is the way to teach!'… so this is working".

For Diana, collaboration was similarly essential for "navigating through each section of the app easily and working in teams to gather initial ideas". For Rachel, collaboration led to effective peer mentoring, where students in the class "were talking and if someone couldn't do something, someone would jump in and say, 'I'll show you how to do that'… and they were helping each other". Alice described similar mentoring, also observing that collaboration did not automatically favour brighter learners: "in the dialogue between the children… that's where you could see, yes, they were on task, they were engaged, and they were learning from each other… and it wasn't the brightest child in the classroom that was offering support and information". Referring to her shadow puppet design task Abigail commented that "it was really good to see them just working in groups, designing it, talking about what features they wanted in their characters... and even in the design process of the shadow puppet theatres, I could see them working so well in teams". For Madalyn, however, the intention for greater collaboration between classes resulted in mixed success: "our original idea was that we wanted to bring our three classes together to do the project, but that was perhaps too many kids in one space working on it together and we would have been better having a smaller group". Commenting on the same inter-class collaboration, Mackenzie observed that some of her students "really liked it because they were given the opportunity to be the leader of the group" but conceded, "this isn't the collaboration we're used to because it was the big group". Dawn also found aspects of student collaboration challenging, explaining that she "had had to remind the kids about how to work collaboratively together using the iPads".

Approximately one third of the teachers interviewed (n=8, 32%) referenced the importance of greater autonomy as an outcome of makerspaces. Abigail described this as a pivotal moment for her, where she emphasised how she learned "to just give them [the students] time" for exploration and discovery:

> …just give them time - and that's how we did… The first lesson in my class, I just let them go for it instead of being very explicit like I normally am. And it was incredible to see what they

> could figure out just by playing around with the app and then share with their peers, rather than me keeping them all together, and we're going to go through it one step at a time.

Sophie described a similar moment where she "gave a lot of student choice, and that worked really well because there are some characters that are quite colourful in my class". For Jenna, the decision to augment an existing task with opportunities for greater autonomy saw improvement to learning in her class. She explained that "for the second part [of the task], they did their own designs… and they were more motivated… and, wow, and they did [that part] so fast and they understood the shapes and [I saw] how quickly they could do it and it was a lot better!". Penny used autonomy as a vehicle for promoting improved peer mentoring, noting that her class "spent the first five weeks in activity time they would have only six iPads in the room and we would play with it basically and I gave them no tuition at all, so they were basically teaching each other". In terms of future directions, Jenna recognised that she would like to promote more "open-ended sorts of activities… something that allows the kids to be a little… to give them access to be more creative, as well… I think that's where I'd like to see it go and have a project to sort of focus on, rather than just one or two or three lessons". As Madalyn likewise explained, "now that this project's over, we want to give them the chance to produce their own item before the end of the year".

Seven teachers (28%) referenced improvements to content knowledge as an outcome. Describing her shadow puppet task, Emma noted that "it [the task] really got us deeper into the science side of light, and that was really important… I think that was a really good way of developing a deeper understanding about the science unit as well". Both Abigail and Mackenzie referenced Mathematics, with Abigail observing that her students' skills in 2D and 3D representation have improved. Mackenzie explained that during the unit, her students "were using their social skills they use in Maths and building and creating, and I could see that they could transfer that into the design process". Other teachers emphasised the role of makerspaces in enabling curriculum integration rather than discretely teaching subject areas. As Alice related, "what I found amazing was the integration across the key learning areas". Jasmine elaborated, "I really liked how it [the unit] allowed me to look at learning as a whole, right, not 'this is English, this is Maths'… Really, I could think about in what ways I could make it more meaningful, I could change it and relate it to all the KLAs". For Ella, the school's emphasis on STREAM learning – incorporating Science, Technology, Reading, Engineering, Arts and Mathematics – was a key concern. In future, she said she sees the design process happening earlier so that students will have sufficient time to build content knowledge across curriculum areas: "next time we do any STREAM project, whether it's 3D printing or a different one, to try to get them to make a product earlier, so that they work more on the refining and testing. Amber agreed, noting that "the idea of STREAM… [is] to be that bit more freer and open with it, and a bit more open… them [the students] leading the way rather than us".

Nine teachers (36%) referenced critical thinking as a key outcome in students' learning in makerspaces. Emma described the design process as an opportunity to develop critical thinking iteratively throughout the process:

> I think the most valuable part was at the end, when we'd printed, and then they had a look at the flaws in their design as well. Like, what broke, what was too skinny, why didn't it create such a good design… And then they went back and changed it [their designs], and I think that part right at the end was really where a lot of the learning took place. It would have been better to do that a bit more earlier on, I think. But they loved it.

For Kirsten, critical thinking was evident in the quality of peer feedback that students provided one another, where students were "critical in providing really constructive feedback through the delivery-design process". Following the completion of her unit, Samantha stated that she was "amazed by their [her students'] abilities to refine their designs", elaborating that prior to the unit, "it was [students would prematurely say] 'my work's finished, we're done', whereas now... some students are realising [saying] 'my original design doesn't work at all. I need to start new. This person over here, theirs really worked. I'm going to work with them'". Madalyn felt that critical thinking was clearly visible among her students having given them "the problem of, 'it's a living thing, what will it need? And what can you make?'" and related how this informed the design of objects for the class hermit crabs. Jane believed that her students exercised critical thinking when transferring designs from 3D sketches to the *Makers Empire 3D* app. As she explained, "some of them came up with some really creative ideas and then designed some things that were really creative… and when they got on to the app, they had to rethink, 'how can I make that thing I've created that was maybe a bit too far?'". Referring to a similar process in her class, Hannah similarly pointed out, "what was a practical task was actually quite complex". Molly found the use of offline making useful for supporting and enabling critical thinking, noting that offline making as an intermediary step actually "made it [the design process] trickier". Alice described several components of her Project-Based Learning (PBL) task, arguing that her students demonstrated critical thinking "with every part of the process… conducting a survey across other classrooms, constructing questions properly… so it was bringing everything in across all the different areas".

Six teachers (24%) commented on how the teaching and learning implementation improved students' creativity. Sophie and Jenna both linked the improvements to the quality of the task design and presence of a longer-term project. Sophie felt that having a problem underpinning the design process resulted in a "creative challenge" that was far more beneficial to students than "one-offs" – self-contained projects that were not "integrated within a much deeper project". Jenna similarly proposed that giving her students "an open-ended sort of activity" gave them "access to be more creative" stressing the importance of having "a project to focus on, rather than just one, or two, or three lessons". For Madalyn, creative thinking was grounded in the problem given to the students in how to support the survival needs of the class hermit crab, saying to students "It's a living thing. What will it need? What can you make?". Hannah felt that the challenges presented to students in her unit of work were considerable, and that creativity was a necessary precursor to technology use, arguing that "you can get all the kids exposed to technology, but it [the unit] was quite complex, so they needed… [to be] creative first, like… visualising something in their brain, like having the task, visualising it, then creating it". Nadia found that "the freedom in creativity worked best in my classroom", commenting that "I had lots of girls engaging in building type challenges, and boys drawn to creative, free make tasks". Despite her students' frustration with the speed at which the 3D printers could print, Amanda admitted that "they were so excited to have the printed object… something that's a physical thing they could use".

For eight teachers (32%), improved problem solving was an important outcome of teaching and learning in makerspaces. Both Ella and Amanda felt that students were able to solve problems effectively without being particularly phased by challenges and setbacks they encountered. Referring to the same task in her class, Jenna felt that students were able to move through trial and error by using the *Makers Empire 3D* app and 3D printers: "they would design it through the app and then see it come to life… Because they couldn't understand, with the boats, again, they'd leave holes underneath... So, it was good when we printed it... [because] they'd look underneath and they'd say: Oh, okay, well I've missed a couple of spots". Madalyn attested the value of presenting students "the problem of 'It's a living thing – what will it need, and what can you make?'" for promoting divergent problem solving in her class. Likewise, Alice emphasised the importance of the problem in the design process, and for ensuring that problem solving skills are appropriately developed. She notes that "initially, we thought we went in with a pretty low-level problem to solve, but… it was really interesting to watch the children sharing their learning… and I said, 'I'm here to guide you, but I want you to talk to each other and try to solve the problem". Sally's main intended use of makerspaces was "to incorporate more making through problem solving", while Kirsten opted for the Toy Designer feature of the app because it "was really tricky for my students to use… and I struggled a little bit as well". For Jane, students' capacities to work with one another to solve problems without needing the teacher was evidence of improved problem-solving skills, where "I haven't given them any help, [and] between themselves, [they have] worked out how to make sure it's [the component] not going to fall off when it gets printed".

Eleven teachers (44%) referred to how engaged their students were when learning in makerspaces. Amanda's students engaged from the first lesson, where she asked them to design an avatar, "building that and stretching the arms and all that, which was hilarious… seeing the student engagement in the app, they love it... and they've very motivated". Commenting on similar use of the app, Dawn rated the engagement in her class as "really high", while Diana argued, "all students [in her class] were highly engaged during the entire project… and I often had students asking when our next *Makers Empire* lesson was". Nadia believed she "definitely observed increase in student engagement in activities that challenged their thinking", whereas Madalyn qualified "when the app worked and when they could print out their thing and put it in the hermit crab tank, they were really engaged, they loved it…". Tim felt he was "able to see lots of kids engaging and talking about what they want to make, and I don't think any group found it boring", and Alice believed her students "were so engaged, with every part of the process". Drawing attention to individual learners, Penny noted that one student in her class often "struggles with reading and a lot of things, and when we do anything to do with Makers Empire, his face lights up". On the other hand, both Kim and Kirsten alluded to problems with students becoming too focused on the buying and selling features within the app platform. Kim's students evidently became "a bit more competitive and a bit obsessed with gaining all those tokens to buy and upgrade characters and things". Observing similar behaviour amongst her students, Kirsten questioned that "maybe it's the age, I don't know… it was definitely a motivator for the students, but in some ways became a bit too competitive, and maybe that was too much of a motivation?".

Likewise, eleven teachers (44%) explained the different ways that makerspaces improved literacy for their learners. Among these references, communication emerged as a key area, with students that were better able to articulate their ideas verbally and in written form. As Amanda explained, "I think once they were refining their designs, the language that they used was excellent, and they were able to describe in a lot of detail what they'd change and how they'd change it and why they changed it". Ella regarded communication as one of "the main skills that really came out" of her makerspaces unit, while Jenna believed that her students acquired language skills for giving and receiving feedback. Kirsten similarly felt that literacy had improved in her class by requiring students to provide "constructive feedback for each other and [them] actually having to explain why they had changed their designs". Amber elaborated on the changes to several of her students' communication skills, suggesting that improvements in communication correlated with improvements to self-confidence and peer feedback:

> I saw a lot of my guys [students], normally I have a few quieter ones, they would just sit to themselves, and be on an iPad or whatever. But because they were so good at it, they were willing to get up and help others. So I think them feeling confident. Communication, I guess. I

> don't know if you'd call it teamwork for some of the ones. They were a little bit like teachers. I could step back a little bit, and I had a few other little teachers in the room that would run around and show the others, which was really good, because being the only one in the room, especially at the start, with kindergarten, was a bit chaotic.

Kim observed that ordinarily reluctant writers became actively involved in their class story by designing and printing characters, and exploring the ways the characters could be used in the narrative, noting, "It was a really nice way for them to be involved, and then when they made the characters they were so excited to be able to contribute to the story and being part of it". Sophie believed that the literacy component in her shadow puppet unit of work worked particularly well "because we linked a lot of literacy with it… and because we picked a book that we [students] had to present [as a shadow puppet theatre]". Alluding to the need to better integrate literacy and numeracy in the curriculum, Madalyn argued that makerspaces represented "the way that education needs to go… because literacy and numeracy are… there's always going to be that focus… but this really works". Sally likewise felt that literacy was embedded in the use of the *Makers Empire 3D* app and had arranged with her colleagues for app tutorials to form a weekly "literacy session". Referring to the holistic experience of teaching and learning in makerspaces, Alice believed that "it was rich in metalanguage and vocabulary". On the other hand, focusing on an individual student with limited literacy skills, Julia regarded makerspaces as "a different way of learning that puts him [the student] on an even playing field… [because] you don't have to have that solid literacy to create and design, to solve problems".

For 11 teachers (44%), increases to students' confidence was a recognised outcome from their use of makerspaces. Among these references, it appeared that success with the *Makers Empire 3D* app and 3D printer was key. Moreover, improved confidence appeared to promote further autonomy. As Amanda explained, "once they had the hand of that [mastered the Blocker feature], they were much more confident, and then they could all go and do that [task] independently". Kim's weaker students gained confidence by participating in a jointly-constructed class narrative with 3D objects and stop-motion animation, while Emma's weaker students similarly "thrived using the app". Dawn's "lower ability kids' confidence improved a lot, and they came up with fantastic, exciting ideas", whereas Jenna's students became more confident communicators. Sophie's students showed increased confidence using technology, "which is a really big, important step for six- and seven-year-olds", while Penny pointed to one student in her class that was now "absolutely busting to answer questions... and just eloquently put it [the answer] into these sentences that I've not heard him speak before". One of Julia's previously reluctant writers was now "a shining star", while Sally described one of her students expressing pride in having designed an object at home in collaboration with her siblings. However, Tim expressed some concern that some students in his class – especially girls – "withdrew at the end of the lesson… When I saw them working together as a group, students who had a louder voice would just lead the whole thing, and the girls would do their own thing".

Related to confidence, five teachers (20%) described the resilience of their students following their makerspaces unit of work. Drawing attention to her students' general reluctance to take risks, Ella described the change in her classroom:

> A lot of them, their resilience [improved]. The kids that would just sort of give up learnt a lot more about persevering with it, and to keep trying, which was good. And the main thing that I loved was that they sort of found problems with their designs and they weren't really intimidated by that anymore. Whereas, I think that for a lot of kids in my class, they find they

> don't want to take risks, or they find like a problem with something is such a big deal, and it's a horrible thing.

Amanda observed similar resilience among her students when they encountered setbacks, noting in one instance that "they were actually so resilient… they knew 'this is either going to work or not', but they weren't upset if it didn't". As she elaborated, "not one child in my class got upset that they had a hole in their boat... [and] they weren't even really comparing to the other kids that much… They knew, this is either going to work or not, but they weren't that upset if it didn't". Describing a similar scenario in her classroom, Amber was impressed that her students "were like, 'well, that didn't work', and they kind of got over it [the setback]". Dawn used frustration and failure as an important opportunity to teach her students resilience, commenting that "my kids wanted to access everything, but they couldn't, and then they actually got frustrated because they wanted to access more. And I said 'you have to earn them, and this is how you earn them. You have to keep practicing using it!'". Sally described using a popular children's story *Sarah Revere the Engineer*, which she believed was instrumental in encouraging her students to respond positively to failure.

Finally, five teachers (20%) referred to improved reflection skills in their classes. Amanda's students exercised reflection as part of the feedback process, and she observed that students were now much better at self-reflections. Samantha similarly found that students were "using that language… and they're talking about it and looking at their designs". Kirsten stressed that "the main thing my students got from it [the unit of work] is that they just learned to be really good, reflective learners". For Sophie, students appeared to be reflecting on the whole design process and learning more about it and themselves as makers. Jenna was pleased when one of her students produced a flawed design, and she saw "her be able to reflect and explain to her peers… 'So my product hasn't worked. I need to go back".

## 12.4 Theme 2: Teachers Discuss Teacher Strategies

Where they were referenced in the data, teacher strategies tended to be informed by responses to Question 3 ("What didn't work so well during the module? How come?"), Question 5 ("What changes would you recommend to the makerspace/s you were using? How come?") and Question 10 ("What were the main things you learnt as a result of running the maker module?"). Eight strategies are referenced as second-order themes.

The most commonly-referenced strategy, 13 teachers (52%) explicitly discussed the use of design thinking in their makerspaces lessons. For Emma, this use appeared to be cyclical, where "we'd go for it [designing] in the app, and then I'd have a look at their designs, and then I'd see that there were some real gaps in knowledge, so we had to go back to the real world". Describing the whole process, she stressed the importance of her students prototyping and evolving their designs:

> I think the most valuable part was at the end, when we'd printed, and then they had a look at the flaws in their design as well. Like, what broke, what was too skinny, why didn't it create such a good design. And then they went back and changed it. And I think that part right at the end was really where a lot of the learning took place. It would have been better to do that a bit more earlier on, I think. But they loved it.

Ella found that explicit instruction played a secondary role to trial-and-error experience in the design process, anecdotally commenting that "if we just told them 'your boat needs blah blah blah', it wasn't until it printed out that they really got it… because they really discovered it hands-on". Amber emphasised the value of students constantly "going back [to the design] and changing it", while Samantha was pleased by her students' abilities "to refine their designs". Amanda believed that the *Makers Empire 3D* app was essential for supporting design thinking in her unit of work, commenting that refining designs "is a skill that they may not have had [achieved] without the support of the app". Sophie stressed the long-term design process over "one off", or self-contained lessons. She argued that design "has to be integrated within a much deeper project… that's where the design process and technology really comes into play. If it's not linked with a deeper project, then you're missing a lot of the challenge and the creative challenge that you can do from it". Kirsten identified the importance of designs that "are a bit out there… a bit too unrealistic" for learning to refine designs "through twisting, turning… providing that constructive feedback for each other and actually having to explain why they had changed their designs". Madalyn believed that one of the most successful outcomes for her unit of work is "taking the kids through the whole design process". She discussed her unit in detail, "where they [students] designed their idea on paper first, they tested it, then they designed it on the app, they printed it, then the idea was that they were going to get to test it with the hermit crab and if it didn't work they were going to get to make improvements and then reprint again". Mackenzie felt that her students started to immerse themselves in the design process, but were ultimately limited by time constraints: "We just didn't have the... enough time, when we had the big group to actually let it, let it, happen, probably more naturally maybe? It was quite rushed". Sally was also concerned that she started the main design component at a late stage in the unit of work. For Alice and Hannah, students appeared to be more metacognitively aware of how they learn in the design process – in Hannah's words, where "they are looking at the process of it, like first of all creating it, doing it digitally and then presenting it verbally as well too". Penny commented that her students learned a lot about the design process through ideation, by "doing so many designs at home", resulting in the challenge of her students "coming up with guidelines" on what to save and what would be best fit for purpose.

Six teachers (24%) referenced authentic learning in their discussions. For all six teachers, connections between the design process and real-world applications of the 3D-printed objects appeared significant. As Amanda explained with her students' 3D-printed boats, "they're more excited to actually test their boat in a real river, down a stream, as opposed to just in a little bucket". Emma's students showed similar enthusiasm for their unit of work culminating in a shadow puppet performance for the school. Moreover, she noted the authentic connections that students appear to make after the performance, commenting that "even the other day, we put up our Christmas tree… and we didn't have a star on top, and one student suggested that we should print one using the 3D printer, and even said 'and we'd need to make sure it has a hole in the middle and something to help it stand upright'… well look at you go!". Sophie regarded that same shadow puppet unit as an opportunity to get "deeper into the science side of light". Both Madalyn and Mackenzie felt that their unit of work enabled students to develop an authentic understanding of living things and sustainability. As Madalyn related:

> …we gave them this problem, that we wanted to buy these class hermit crabs and we just gave them an empty tank and said, we can't have the hermit crabs yet, because their tank's empty and they're living things. So we kind of tied it in to what we'd already been learning the previous year with science and everything like that. So it kind of built on what they already knew. So that worked really well because they had good ideas and they really did enjoy, when the app worked and when they could print out their thing and put it in the hermit crab tank, they were really engaged, they loved it.

Mackenzie likewise felt that her students made some real-world connections, though conceded that if she "had done it more, like more lessons through the week, perhaps there would have been that more of a connection". Julia echoed this finding, conceding that 3D design and printing "is a bit removed from their [the students'] world" adding that "the learning that I gained from the professional learning days was that 3D printing [is applicable] in the world today, for medical things, dental and stuff like that… so I found my class was a bit removed from that".

Seven teachers (28%) referenced the need for explicit instruction at times in their makerspaces lessons. In particular, teachers viewed modelling as a way for students to understand important parts and ends in the design process. Madalyn suggested that such modelling is necessary for giving young learners a clear idea of what they can design. She explained that, when first working with the *Makers Empire 3D* app, students "just blobbed a cube down and then found some kind of triangle for a roof, but of course that was solid, so the hermit crab couldn't go inside, you know? So then we modelled for them with Lego how they would have to use multiple blocks to make…". Mackenzie saw explicit instruction as a "prerequisite" for students understanding what is required and how they should work, especially when collaborating in large groups. Amanda saw whole-class instruction as less effective than explicit instruction in small groups, where the teacher was better able to check in with individual learners. For Amber, students had difficulty following instructions without modelling, while Emma believed in the value of "purposeful instruction" adding that "when there were flaws in their designs, I was more purposeful with [instructions like] 'if you want this to happen, come over here and I'm going to demonstrate something'". Dawn viewed modelling as an effective strategy for differentiation, elaborating that "you can get your higher kids coming up to the Smart Board to facilitate that [modelling]", while Julia saw explicit instruction in the form of "real structured goals for them [the students] along the way" to keep students engaged and on-task.

Six teachers (24%) discussed offline making as a supporting element in the design process. Emma's students constructed "cardboard shadow puppets, for them to test, look at light, then go back to [the] *Makers Empire* [app] again". Amber's students similarly found constructing foil boats particularly helpful for better understanding buoyancy. Jasmine adapted her approach mid-unit based on misconceptions and difficulties her students encountered, explaining "we decided, when they drew their designs, the concept… They went and practised on the app, but it was just a little bit too hard to understand that, from 2-D to 3-D. So then we went back, and we made the clay models first, and that helped them understand the shapes of how to make their shadow puppets". Abigail utilised "paper… to give them an idea of what [they wanted] their boats to look like… and Lego… for them to physically make it, so they could see what it might look like", adding that "they could use their Lego design to then model it when they're making it on the app". Mackenzie noted that her class did "a lot of hands-on type of creating" with offline materials, which "was totally a new thing for them". Molly alluded to the value of offline making to add sophistication to the task, observing that her students, "found the app much easier, because they could see the shapes, they could mould it, and they make the height, width and whatever… so transferring that [offline design to the app] was trickier than just using the app itself".

Five teachers (20%) underscored the value of students providing constructive feedback to their peers during and/or following the design process. Kirsten asserted that her students "have to provide that feedback to refine their level [of work]… and my students, every time, got better and better at providing that feedback". Jasmine saw the feedback as a means for students to "guide and teach" one another instead of the teacher always providing the feedback. She was pleased that, throughout the unit, her students "were becoming peer coaches themselves, which encouraged them on a deeper level". Samantha believed that peer feedback is ultimately necessary for what she described as the "ownership of changing their designs", where students took ownership of the need to refine their work so that it was fit for purpose. Abigail described her decision to avoid using explicit instruction at the start of the design process, noting that "I just let them go for it instead of being very explicit like I normally am… and it was incredible to see what they could figure out just by playing around with the app and then share with their peers, rather than me keeping them all together, and [saying] 'we're going to go through it one step at a time'". Rachel described successful peer feedback in her classroom, drawing attention to her decision to "not give them too much support" and finding that "they were helping each other… if someone couldn't do something, someone [else] would jump in and say, 'I'll show you how to do that'".

Play – and especially open-ended play – was framed as an important strategy by 11 teachers (44%). In many cases, this involved experimentation and discovery using the *Makers Empire 3D* app. For example, Amber noted how much her students enjoyed "just playing around and making funny things" in the app, whereas Abigail observed that "it was incredible to see what they could figure out just by playing around with the app". Sally's students enjoyed play through making avatars, while Julia likewise observed that "we spent many sessions just exploring [the app], so they got it out of their system to make their little avatar, because that's their reward… it's what their world is to make those things". Rachel noted that she "did give the kids lots of time just to explore with the iPads on their own". Elsewhere, for Nadia, play was a natural fit for the class, where "the kids are so used to 'free roam' activities, so this helped in structuring our makerspace". Emma viewed play as a form of "trial and error" for informing her of important skills and concepts that she needed to address: "we'd start doing one thing, and then I'd realise they needed more background knowledge". Mackenzie and Madalyn stressed the value of play, in Mackenzie's words, in the form of "a lot of hands-on designing activities and trial and error". Hannah saw play as a "practical process… getting kids onto the iPads and manipulating [designs]", while Penny decided to "spend the first five weeks [of the unit] and we would play with it [the app] and basically I gave them no tuition at all, so they were basically teaching each other".

Finally, the less commonly-referenced areas of student demonstrations (n=3, 12%) and third-party tools (n=2, 8%) were nonetheless viewed by teachers as useful for supporting learning in makerspaces. In Amber's classroom, several students "are so good at it [designing with the *Makers Empire 3D* app], they were willing to get up and help others… they were a bit like teachers". Lacking some confidence in her own abilities, Sally decided to "borrow two of Penny's kids… who came over and showed them [her students] how to use the QR Pattern Reader and to get on [to the platform]". Penny explained that during the unit of the work, "I had the kids demonstrate, and we had the document camera, so we had the iPad sitting on the desk and the child would demonstrate how to do a certain tool, and I took a screenshot of it". Both Samantha and Jenna made use of the Seesaw social learning management system app on their iPads. Samantha's students "worked on Seesaw and kept a journal", while Jenna used the same app, "and the kids actually drew and designed, and labelled their gadgets". While it received limited reference in the data, both teachers underscored the importance of this app as a way to manage the design process in an online environment. Samantha thought that in future, "you could record students, so they could model what they were doing", while Penny sees the app as crucial "in my planning process".

## 12.5 Theme 3: Teachers Discuss Challenges and Opportunities

Teachers referenced challenges and opportunities throughout their discussions, often in response to Question 3 ("What didn't work so well during the module? How come?"), Question 5 ("What changes would you recommend to the makerspace/s you were using? How come?") and Question 13 ("What recommendations can you make for professional learning in order to best support you to run maker modules in your classes?"). Seven second-order themes emerged in the analysis to capture the range of challenges and opportunities encountered. The use of both "challenges" and "opportunities" in this theme reflected the fact that teachers were often able to frame challenges positively and discuss how they responded to the challenge, what they learned from it, and what they would put into practice in future teaching and learning in makerspaces.

Ten teachers (40%) referenced 3D printing in their discussions. 3D printing was included in this category mainly because teachers often expressed frustration with the time it took to 3D-print, problems with the hardware and difficulties coordinating 3D printing across several classrooms. However, teachers also recognised that 3D printing represented a valuable opportunity to test designs and celebrate students' achievements. Jenna described her lack of knowledge of how 3D printers work as a barrier: "I think if we had more understanding of how the actual device works mechanically as well, maybe then we'd be able to, you know, problem-shoot". Sophie felt confident in her use of the *Makers Empire 3D* app but concedes that a 3D printer hardware issue "is something that isn't within our capabilities… so we need more support for that if something happens with the hardware". Madalyn said she would like to provide students with the opportunity to create and 3D-print original designs, but was "concerned because we saw how long it took to print out some things and we thought, 'well if they don't finish their designs until Week 7, and then we need to print out all the designs and get them to be able to test them and evaluate them and reflect on them, [we couldn't do it]'…". Kim stressed that the main concern in her unit of work "was a time thing… if we had more time, we could have printed one [object] at a time, and made them bigger, but because we were trying to do it quickly, we all had to fit four on the print panel at once". Amanda's students were "most frustrated with the fact that it just takes so long to print". Sophie regretted that she "had so many technology problems with the printer… that really minimised [impeded] our efforts to finish the project…. And it's a big problem, because we still haven't completed it [the project]". Elsewhere, teachers presented a more positive assessment of 3D printing. Amber saw 3D printing as the pinnacle of the unit, elaborating, "being able to print it out, I think that just made it for them, really… everything they made, they wanted it all printed!". Ella's students "loved so much watching their own designs print, so they'd be like [would say] 'It's actually printing!'". Emma was delighted that her students were now suggesting other objects that could be 3D-printed to serve various functions in their classroom, such as a star for the class' Christmas tree. Referring to 3D printing to test her students' designs, Jenna felt that "it was good to design it on the app and then print it… to refine it again and fix it up". Samantha saw 3D printing as important for clarifying and correcting students' misconceptions, explaining that "one of my students printed… one of the blocks was in the air, and trying to make him understand, well, it's not connected to anything, so we can't print that. But he still couldn't understand it. But then we printed it, and then it came out as a big blob because it didn't work". Julia was concerned that the location of 3D printers in other classrooms – rather than her own – had meant that "my kids haven't seen the 3D printer in operation", and she decided to "traipse over [with her students] to look at the 3D printer setup because it's so important they see it".

Differentiation was both a challenge and opportunity that seven teachers (28%) identified in their discussions. Teachers in this group frequently expressed concern about lower-ability students, and often cited students' low literacy skills as evidence of their ability, though the comments suggested that makerspaces positively impacted on these students. As Emma related, "one thing that stood out to me in particular were some of my lower ability students, and how well they thrived in [the makerspace]… I've got one boy in particular who struggles with writing, struggles with reading, can't communicate well with others. He's just one of those little children". Jasmine echoed this finding, saying that "even for my lower [ability] ones who do not have the confidence in writing or reading, they really went ahead and just created their designs". Dawn found that for her "lower-ability kids, their confidence improved a lot", while Jenna identified improvement in her "lower [ability] students, who beforehand when we did our previous two terms in STEM, they hadn't been able to communicate to me why their design didn't work out". Hannah recognised that in her class, "kids are at different levels, and some find it difficult with problem solving and manipulating even the most basic things" and that she needed "probably a little bit more time with those tools" to support weaker students. Both Penny and Julia found that weaker students had improved in their confidence and communication skills.

Eleven teachers (44%) discussed the challenges and opportunities inherent in working in their physical learning space. The need for flexible learning spaces was most often referenced, with several teachers discussing the advantages of having a space – or spaces – they could adapt to suit the needs of their learners. Ella and Amanda both discussed the advantages of having an outdoor makerspace in their school. Amanda believed she was "very lucky to have the outdoor makerspace, because for Kindergarten that was a big component for our project". Ella added that the space "really informed the Science concepts… [and] gave them a lot more context and understanding about what they have to then put into that [their designs]". For Emma, having "real life materials" was essential to her space, "in that we could have a torch set up and a little fake shadow puppet theatre, so that when they were designing, they could test at the same time". Dawn observed the students' different preferences for working in her space, finding that "a lot of my kids wanted to go under tables, wanted to go into corners… they wanted to do that naturally". Abigail stressed the importance of flexible furniture for makerspaces to work, adding that she was lucky because "our class is sort of set up like that anyway". Hannah described her space in detail, explaining how different components best support learning in her class:

> The kids of mine that were being observed were sitting on the orange jelly bean table and that gave them a lot of space to actually move. And then there was that space there where you could sit and demonstrate or there's another child that could sit. I think that extra space the kids need to be able to, you know, be a bit more or have space for the iPad to be a bit more created. Because it makes for each other to do a bit more sharing rather than being across from each other, they are right next to each other. But it is just like you can get a chain of conversation going, you know, and across other people also having… You know, appropriate, I'm not saying, but it's not expensive the furniture, but having that for collaboration might be, like Alice was saying, a particular group who they've got a couple of jelly bean tables, a couple of the stools and having in the room, you know, they might explore, they might make there, and go and explore on the iPad there or draw their creation there.

Elsewhere, teachers expressed concern about working in their space and across other spaces. An itinerant school leader responsible for supporting several teachers in their makerspaces, Alice conceded that she needed to constantly "go packing up and unpacking" materials for different makerspaces in the school and would like to have spaces set up all the time. Madalyn, Mackenzie and Tim all expressed concern about their decision to combine three classes in an open-plan space. Madalyn simply concluded, "that was too many kids working in one space… and we would have been better [off] having a smaller group". Mackenzie remarked, "this isn't the collaboration we're used to, because it was the big group", whereas Tim found "it was quite loud, with 60-odd students in the one classroom".

Related to the physical space, resourcing was a concern raised by seven teachers (28%). Alluding to the at-times lack of support she felt, Mackenzie stressed knowledgeable support personnel as crucial, identifying a class with which to share problems, concerns, and success as key. Alice expressed concern over the school's limited technology resources, which meant that she had to set up and pack up devices across multiple classrooms and added that "we could definitely do with some more iPads". Amanda found her class "is a bit limited, because ten iPads for 21 kids is a bit tricky", while Sophie and Jenna expressed concerns over 3D printers not working properly. Nadia conceded that in her classroom, "technology was hit and miss, and I guess that just goes with the nature of it… but the biggest troubles we had were the inconsistent use of iPads, logging in problems, and offline/online dramas". Madalyn explained that her "biggest problem is that the [education] department's Wi-Fi is very slow… and sometimes a whole lesson would pass and it [the devices] still hadn't logged in".

The challenges and opportunities of working with the *Makers Empire 3D* app was an area of focus for 11 teachers (44%). Teachers and their students viewed using the app as challenging – especially with reference to specific features in the app – but that successfully designing 3D objects was viewed positively. Amber's class exemplified the challenges and opportunities of using the app well, but she admitted that she "should have started with Blocker first. I went straight into Toy Designer, and quite a few of them [the students] were getting frustrated, not understanding the dimensions of it and how to make things attached, and they just got a little bit annoyed with it". She further added that "as soon as we went to Blocker, most of them could do that straight away… and they liked playing around with it and adding little extra pieces on. A few found it a little bit tricky, but not too much". Kirsten similarly found that "Toy Designer was really tricky for my students to use… and I struggled a little bit as well". Amanda's students gravitated towards "the bits [the features of the app] that are more familiar to them", whereas Kim's students seemed to "pick it up quickly using *Makers Empire*". Emma's students initially "used the Shaper tool, which they picked up really quickly". However, Jasmine believed that first-time use of the app was difficult in general: "at the beginning it's tough. You push the button and go: It's not doing what I want it to do. So, it's definitely, probably not the most user friendly for beginners…". Sophie likewise believed the "3D platform is difficult, especially for younger children. They can't understand that visualization of, if you spin the platform, you're looking at a different orientation". Abigail argues that understanding concepts necessary for 3D design, "and then twisting it [rotating the design], having to actually use the ruler and all of that… these are quite hard concepts for a younger stage". Elsewhere, teachers pointed out the opportunities of working with the app. Amanda explained that the app "supported the kids a lot, because they were able to make something that they may not have been able to make if we used cardboard, or foil, or whatever". Samantha thought that recording screens and journaling regularly help her students to navigate the difficulties of using the app. Dawn's students were so excited, that they "want to access everything" in the app platform, whereas Diana felt that with support, "students are able to navigate through each section of the app easily, working in teams to collaborate and gather initial [design] ideas".

Nine teachers (36%) referred to time as a challenge and opportunity associated with makerspaces. For the most part, the implication was that they feel time was insufficient for achieving all they had hoped for in their teaching and learning in makerspaces. For Amanda, Kim, Emma, Sophie, and Madalyn, time was most closely related to the length of time in 3D-printing objects. Emma pointed out that if 3D printing were faster, "we could design, print, design print, and use that [iterative] process, but because we were constrained in our time, we went back to cardboard to see how that worked before we changed our designs". Elsewhere, time appeared more of a concern in relation to managing the project as a whole. For Ella, time appeared related to sequencing decisions when she pointed out that "normally we do a lot of context and building, and the final product is just one chance…. [and] I think next time I'd love to do [the designing] earlier, because that's something my kids really excelled at – refining their designs". Abigail admitted that she started with only one makerspace session each week, later adding further sessions. Mackenzie felt that one term on the project was insufficient, and "maybe if we'd had more time, like probably two terms… we could have taken a little bit more time and changed the way we're doing things". Madalyn conceded that her idea of allowing students to design and print original objects in the final three weeks of term is untenable.

Finally, design translation emerged as a point of reference for eight teachers (32%). As explained earlier in the report, translation refers to the transferral of designs from one medium to another, such as the commonly-referenced offline-to-online translation that was identified in the lesson observations. In the focus group interview, teachers seemed to recognise translation as both a challenge and opportunity, seeing the challenges as mainly conceptual, while identifying opportunities for critical thinking and problem solving. Jasmine described the problems with requiring her students to produce cube-shaped boats to test buoyancy, observing that "when they want to actually come up with their own designs, it [the task and process] made it restricting for them". Referring to the same task, Kirsten expressed concern at "having to explain to five-year-olds that, 'yes, your boat included all of these features, but because it's now a quarter of the size of it, that's why your teddy bear's not going to fit in'". Alluding to the impracticalities of 3D-printing many of the students' initial designs, she summarised that most of the designs "were a bit out there, just too unrealistic to create". Jane similarly refers to the challenges of working with her students' "grandiose ideas". Kim, Amber and Abigail all drew attention to the challenges of working with ratio, dimensions and sizing when translating designs in the app to 3D-printed objects. As Kim elaborated, objects "look quite big and a decent size when they have it on their little iPad screens, but then when they print it, it's like this little [very small]… so some children had a really hard time understanding the dimensions for printing". For Diana, the constraints inherent in translating designs from initial conceptions to 3D-printed objects was framed positively: "I could see the many successes of running a project like this. I saw that the students took a problem, were able to identify a problem, the constraints, planned their ideas, created their ideas, modified, printed, reflected…". Molly similarly believed that her use of offline making made the task "trickier, because students can see the shapes and they can mould it, and they can make the height and width".

## 12.6 Theme 4: Teachers Discuss Teacher Transformation

The fourth and final theme explored teachers' perceptions of how teaching and learning in makerspaces transformed them as teachers. The final question group (Questions 10-13) chiefly informed the themes captured for this theme:

10. What were the main things you learnt as a result of running the maker module? This can relate to teaching in makerspaces, teaching with technology, or teaching more generally.
11. Did you notice any changes in your attitudes or approaches towards teaching? If so, what were they?
12. What aspects of the professional learning support were most useful to you in preparing you to run the maker module with your classes?
13. What recommendations can you make for professional learning in order to best support you to run maker modules in your classes?

Four teachers (16%) discussed how their planning processes became more collaborative because of their participation in the project. Mackenzie described this as an organic, exciting and flexible process of researching and contributing ideas as the unit of work takes place, and she saw this form of collaboration as like her students collaborating in the classroom:

> That's the exciting part about it [the unit] because when you go on their [*Makers Empire*] website you can see, you know, when we were originally having a look and there was, "oh that would be good, that would be great!". But along the way, we would do the same thing [in our planning] as the kids are doing, as we did for our own unit, we would be doing the same, "oh but I could do this, and you could add to it", or take the best bits that suit you when you're teaching I guess.

Madalyn echoed this sentiment, stating that "it was good because as we were going along we'd be talking to each other and saying, 'this would be better next time, and we would change this next time', you know? We don't get to do that with every unit we teach. You just don't get that opportunity". Alice also found that her experience collaborating with colleagues was like students' collaboration: "I found [it was] like the children, collaboration and working with a colleague, who inspired… We inspired each other to take the risk even just getting the 3D printers up and running…". Penny fond that collaborative planning led to greater transparency with her practice: "we were talking about it in the staff room, which we don't often talk about our practices… You know, you whinge about kids or you talk about kids and ask for advice for the kids, but we don't actually talk about what we do for teaching, so we are actually [now] talking about what we were doing".

Five teachers (20%) identified greater flexibility in terms of their abilities to adapt their practice and, in Ella's words "go on the journey". Emma described this as being comfortable with "a lot of trial and error… [where] we'd start doing one thing, and then I'd realise they needed a lot more background knowledge". For Sophie, flexibility was an integral part of her planning, with "a much more flexible approach". She elaborated that "although we'd scoped out some lessons for it, none of them worked out to plan, but we just said, 'ok – this lesson we're going to do this'" and emphasised that the value of "having that opportunity to allow the unit to progress as it did, given whatever circumstances were defining it, and then allowing us more input into how it went". Julia described a somewhat similar approach, saying that "although I didn't deviate a great deal, I did change things according to how it went". Samantha simply stated that her teaching "wasn't so structured, and I let it flow".

Teacher-learner partnerships emerged as an important area of focus for showing how seven teachers (28%) transformed their practice. For most in this group, these partnerships involved the teachers learning from the students, seeing themselves as learners, and not being afraid to ask for help from the students or their colleagues. For some, such as Ella, partnerships also involved relinquishing control as the teacher, where, as she described, she "handed it [the control] over to the kids… and we'd always have some exploring time whenever we tried something new… and come back together to share things we'd learned". Similarly, Jenna felt that she "learned that the kids were teaching me at some points", and that she was able to "step back a little bit and actually let them [the students] learn through discovery… and show me other things that I didn't know". Diana admitted that she had to become more comfortable with the reality that "sometimes I would not know the answer to their [students'] questions, no matter how hard I tried to figure it out". Alice described being more comfortable with her occasional lack of knowledge and skills, pointing out that she is now more able to rely on students and colleagues for help:

> One of the good things was, we were all learning with the children and along the way we communicated that with them. At one point, I was actually in a classroom last week and I couldn't get the shape to sit flat… And I tried and tried and tried, and the child was getting

> frustrated. She could see that I was finding it challenging as well, which is really good for them to see that. And I said, why don't you go into [the other teacher's] room because I know that she is really good at attaching the shapes together. And to see that I had asked for help from another teacher, I think was really powerful for the child to see that.

Molly identified value in simply "fiddling with things", making mistakes and learning from students during the design process. Jane reflected that "it's nice for the kids to see us learning… and one of my girls said the other day,' oh, you never stop learning all your life'. And I thought, she's seeing, it is a process she is seeing, and I'm actually learning, and most of the other things we never show that we are learning!".

Nine teachers (36%) explicitly discussed how their pedagogies had changed following their involvement in the project. For Emma, group work was far more effective because she now encouraged her students to engage in peer mentoring, feedback and reflection, adding she now felt "this is the way to teach!". She also recognised that maker technologies should be integrated into longer design projects, adding "that's where the design process and technology really come into play… if it's not linked with a deeper project, you're missing a lot of the challenge…". Jasmine conceded that her school has previously emphasised "ordinary learning ways… because you know, we start off with pen and paper… but it [the makerspace] gave them the understanding that they can learn in other ways". Jenna found that posing a problem as part of her approach to design thinking meant that students had "access to be more creative" and stating, "I think that's where I'd like to see it go, with a project to focus on rather than just one or two or three lessons… something where kids can work together to produce something of a larger scale, maybe". Diana observed that the unit of work represents "the first Project-Based Learning [PBL] program that I had planned and taught myself", adding that "as I was new to the idea of PBL, I was introduced to its many benefits, including collaboration, team work, creative thinking, critical thinking, student-centred approaches, participation, increased enthusiasm, communication skills, and evaluating skills… and I have changed my practice to incorporate more PBL styled lessons and programs". Mackenzie observed that the unit made her focus more on technology in her teaching, significant because she was "a very face-to-face, hands-on kind of [teacher]… it's [technology] not something that's big in my classroom". Madalyn now saw herself working "from an inquiry base", whereas Alice similarly saw herself as becoming problem-based and inquiry-oriented in her approach to pedagogy, "rather than simply telling children the problem". For Hannah, the unit had galvanised her commitment to meaningful learning, where "we need to have in our mind, and the kids need to have in their minds, what is the intention behind it [the learning]? Is it to be creative? To design?".

A broader attitudinal change in mindset was something that 13 teachers (52%) articulated in their discussions. In most cases, this represented a subjective view of how previous attitudes were now being rethought, and what that might mean for their teaching. Ella found that during the unit of work, she "stepped back a lot more than I would normally, that I was a lot freer and sort of less planned… it [the learning] was really driven by them [the students]". Jasmine now saw the limits of the "ordinary learning ways", whereas Jenna now realised that "we give so much" in terms of explicit instruction and direction in how learning should take place. Kirsten described now "stepping back" in terms of re-evaluating her own expectations of what learning should look like and allowing students to take more control and avoiding the urge "to help them straight away". Abigail similarly described "learning to give them [the students] more time… instead of being very explicit like I normally am". Alice realised that she had been "telling" the students rather than letting them discover and share their learning with each other. Both Diana and Nadia reaffirmed their belief in student-centred pedagogies. Diana stated that the project "affirms that I am a teacher who believes in a student-centred approach and less of a teacher-centred approach", while Nadia stressed that "as a teacher, I have learned to trust more in the kids, [because] they really do rise to a challenge, and they exceeded my expectations in their creations". Mackenzie was reassured by her realisation that "I'm not scared of technology… and it's made me want to look into it more". Tim conceded that "at the beginning of the project, I did have low expectations of my students… [but] I was very surprised at the end". Madalyn described an interesting "love-hate" relationship with change: "I'm in two minds. I like change and I also hate change but, I liked this because it kind of was something different, you know? Like I've been teaching Kindergarten for five years, and while I do change my units every term and every semester, it was a total rewrite which was really nice, and I enjoyed it". Molly felt that learning from her students was a very new experience – a "total eye opener" that will inform her future practice moving forward.

Four teachers (16%) referenced professional learning as part of their teacher transformation. Jane regretted that she was only able to attend one of the training days but was pleased that she managed to engage in informal professional learning activities through collegial support, and through trial and error. Mackenzie believed that an in-depth focus on technology should inform her professional learning moving forward, adding "I've got to think, this is something that's important and that will benefit the kids and benefit me as well, and I still don't know enough about it, but I've been listening to these two [colleagues]". Madalyn identified team teaching as a useful professional learning strategy for scaling success with makerspaces throughout her school, elaborating:

> I would feel comfortable enough, probably with these guys' [colleagues'] support to run professional learning on how to use *Makers Empire* and give them some ideas about projects that they could maybe initiate. Because I think one of the best things about *Makers Empire* is that they're obviously very considerate about... They've already got a lot of ideas for programmes and ways you could integrate that into your units and things like that, so... I think teachers today are time poor and there's always another thing added to the top of the pile but if you can say, you don't need to reinvent the wheel here, but look at what you could put into this existing unit that you have and look what's already here so you're not having to start from scratch.

Alice felt that the best form of professional learning is informal, having occurred throughout the unit of work. She admitted, "we were a little bit apprehensive to start with because we found the need to get in and play with them ourselves".

Finally, five teachers (32%) referred to improvements in their confidence to teach. As a first-year-out teacher, Diana now felt far more confident in her teaching ability, even though she was not always able to answer students' questions. Mackenzie felt more confident in her use of technology, and confident in her belief that technology was important for learning. Madalyn had some doubts, noting the places in the unit where "we were thinking, 'oh, this looks really hard'" but realising "even half way through [that] it works, and the kids love it…". Alice explained that she gained confidence by collaborating with colleagues, admitting, "I would never have done it [the project] by myself". Molly described the initial boost to her confidence "the very first time I made something", adding, "it was like 'I want to print mine!' – I was so excited… and you could see how the kids [similarly] get so excited when they create something". Hannah described the effect of her own confidence on that of her students, explaining, "well, I'm confident at having a go, so you have a go… then the kids think 'if the teachers can do it and they can model it to me, then I can have a go'… they then have the 'have-a-go' approach". She added that "I think it's not only just with technology, but in everything you do for the kids… when you get up there and you present a lesson, the kids know the teachers had a go, so they'll have a go".

## 12.7 Teacher Future Intentions

At the end of each of the focus groups, teachers were asked whether, given free will and opportunity, and knowing that all results would be reported anonymously, they would choose to run a makerspaces unit of work again. All 24 of the 24 teachers interviewed (100%) indicated that given free choice they would choose to run a makerspaces unit of work in a future term or year.

## 12.8 Limitations of the Teacher Focus Groups

Although many second-order themes were explored across the category system, revealing teachers' insights on their experiences with makerspaces, there are some limitations that warrant further attention in relation to this dataset. First, although 25 teachers collectively participated in the focus groups, most second-order themes are referred to, at best, by 13 teachers (52%). The short interviews coupled with a relatively large number of questions posed to groups of teachers presented challenges for the research team. Reporting smaller numbers of teachers referencing a given theme did not mean that the theme was not an area of interest or concern for teachers that did not address it; rather, it suggests that all teachers did not have sufficient time or opportunity to address all the questions in the interview protocol. The strategy of grouping questions proved useful for covering the full range of intended areas, and the first question group was posed to every teacher in the focus group. However, subsequent questions were only covered sporadically, so it is not clear whether, given further time, other teachers may have chosen to address other questions.

## 12.9 Teacher Focus Group Analysis: Summary and Concluding Remarks

Across the responses to the 13 interview questions, a comprehensive range of themes emerged in the analysis. The diversity of ideas and insights shared speak to teachers' robust, collective understanding of teaching and learning in makerspaces – the positive outcomes that emerged, the strategies employed to realise these outcomes, the challenges and opportunities faced and the transformation in teaching practice that resulted.

The "outcomes" theme was similar to themes used elsewhere in this report and continued to capture teachers' perceptions of the many learning benefits of using makerspaces. Teachers continued to remark on improvements to enterprise skills, learning behaviours and content knowledge. Strong, detailed references provided insights and evidence in relation to the many ways that students demonstrate collaboration, critical thinking, problem solving and autonomy. Interestingly, literacy seemed to be a bigger area of focus in these data than in previous analyses, with several teachers linking improved literacy to improvements in both communication and confidence. In turn, teachers were able to describe how improved confidence has often led to greater participation in class, students asking more questions, and students feeling proud of their achievements. Teachers sometimes presented these small successes as "mini case studies" of the reluctant and less able learners. As such, these findings suggested that benefits should not be taken in isolation, and that individual students' stories of success are just as important those of whole class success.

Teacher strategies continued to be important, with teachers presenting and discussing what amounts to a toolkit of evidence-based strategies that they have honed well throughout their involvement in the project. More open-ended strategies authentic learning and play continued exist alongside the more teacher-centred strategies of explicit instruction and modelling. Interestingly, the “feel your way as you go” approach (as suggested in Cluster 5, encompassing autonomy, play, collaborative planning and flexibility) was important for their practice as well as their students' learning. Teachers seemed to feel the need to step back and allowing the learning to take place for the students. As the same time, they felt they should be flexible in their planning, and acknowledge that the learning that takes place may not always go to plan.

The “challenges and opportunities” theme seemed appropriate at this stage of the project, where teachers very often saw both positive and negative aspects in the difficulties they faced. As the teachers themselves seemed to suggest, whether something is either a challenge or opportunity is often a matter of perspective at the given time. Although teachers continued to describe problems such as limited time, a lack of resources, malfunctioning 3D printers and inconsistent Wi-Fi, they seemed to accept their role as pioneers implementing makerspaces in their school community. Their efforts to resolve the many issues they faced would have a lasting positive impact on the school community and make the process smoother for other teachers following their example.

Finally, “teacher transformation” was an important theme for this stage of the study. The theme appeared best marked by the references to changes in mindset, pedagogical change, along with the emergence of teacher learner-partnerships. The mindset appeared to encompass the need to let go, trust students and allow more unstructured learning to occur. Pedagogical change appeared related to mindset, with problem-based and inquiry-oriented pedagogies coming to the fore, and an acceptance of design thinking as an effective toolkit for promoting these pedagogies. Teacher positivity surrounding learning and teaching in makerspaces was reinforced by all 24 teachers (100%) indicating that they would choose to undertake makerspaces units of work in future.

# PART V

# Summary

# 13 Findings

*This chapter synthesises the analyses of the nine data sources to present findings according to the six research questions. Makerspaces-based learning using 3D design and printing technologies was found to develop a broad range of 21st century learning skills, along with design thinking, literacy, numeracy, scientific understanding, technological capabilities and resilience. Students were observed to develop a range of design thinking capabilities including discovery, interpretation, ideation, experimentation, evolution, and the ability to translate between physical and digital designs. Learning was found to be supported or constrained by the balance of explicit instruction to open-ended inquiry, the general pedagogical strategies used, the effectiveness of technological resources, the task sequencing, the design of the spaces, and students' background knowledge. Maker activities using 3D technology resulted in very high levels of learner engagement and desire to undertake further 3D design and printing activities in school and beyond, though off-task behaviour was sometimes observed as a result of technological availability, collaboration difficulties, and gamification aspects of the software. The well-structured, pedagogically grounded, hands-on and situated professional learning gave teachers a better understanding of how to teach in makerspaces and the skills required, though teachers indicated a desire for more time to master the technology and more responsive online support. To effectively develop and practise their maker pedagogical capabilities, teachers need access to reliable technology, collegial support, teaching resources, appropriate makerspaces,* *time to develop their capabilities and lessons, and a school culture that supports inquiry-based learning.*

## 13.1 Introduction to Findings

This chapter synthesises research findings from the various datasets to address the six research questions that directed the study. Each data source was reviewed with relation to each question, with quantitative and qualitative findings from across datasets being triangulated to promote reliability of findings. Indicative examples are provided to clarify meanings, with further details and evidence available in the previous analysis chapters.

## 13.2 RQ1 What do students learn when undertaking maker activities?

**When undertaking makerspace-based activities, students were observed to develop creativity, problem solving skills, critical thinking, inquiry capabilities, design thinking skills, collaborative skills, autonomy, literacy, numeracy, scientific understanding, technological capabilities, communication skills, reflective thinking capabilities, and resilience.**

High levels of **creativity** were noted in 22 of the 31 lessons observed by researchers (71%), where the plans, solutions and artefacts students created clearly reflected original thinking. The development of creative capabilities was frequently mentioned by teachers in their reflective journals – for instance, in Jasmine's class, where students rapidly ideated 180 designs in a single lesson. Creativity was often discussed in the teacher focus groups, where many noted the prevalence of creativity through, in Hannah's words, "exploration using concrete materials, writing, drawing and technology". Creativity was also a commonly-reported outcome in the post-implementation questionnaire – for example, where Kim explained that maker tasks "allowed the students to show their creative side and to investigate situations to improve on".

In-depth **problem solving** was noted in 18 of the 31 lessons that the research team observed (58%). In their reflective journals, teachers often framed problem solving as a positive outcome, for instance, as Alice noted, when students "are quick to identify a problem and determined to find a solution". The development of problem solving capabilities was also one of the most frequently mentioned outcomes in the teacher interviews, such as when Jane observed, "I haven't given them any help, [and] between themselves, [they have] worked out how to make sure it's [the component] not going to fall off when it gets printed". Problem solving was also a frequently mentioned outcome in the post-implementation questionnaire, with comments such as Rachel's: "[students] have learnt that problem solving is a part of their everyday living, and that while they can suggest multiple solutions and ideas to solve problems".

**Critical thinking** was observed in in 15 (48%) of the lessons observed. In Molly's lesson, for example, critical thinking was evident when students were required to think carefully about decisions like how to best customise the design of their keyring to meet the needs and interests of the teacher they interviewed. Teachers also frequently cited critical thinking in their reflective journals, such as when Alice observed that there were "high levels of refinement of designs". Emphasis upon critical thinking also occurred in the teachers' focus group interviews, where Emma commented, "when we'd printed, and then they had a look at the flaws in their design … and then they went back and changed it [their designs], and I think that part right at the end was really where a lot of the learning took place". There was a marked increase in the number of times critical thinking was mentioned in the pre-professional learning questionnaire (n=4) to the post-implementation questionnaire (n=17), indicating that this may have been one of the unanticipated outcomes for teachers.

The development of **inquiry capabilities** was documented in five (16%) observed lessons. The capacity of students to conduct open-ended investigations was also raised an outcome by eight teachers in the post-implementation questionnaire, with comments such as Samantha's indicative of the broader theme: "[students] had gained skills in their inquiry process… and are able to use these skills with technology to design projects". Other teachers observed how, because of the module, students were "able to investigate real world problems independently" (Jenna) and had become better at "asking more specific questions" (Rachel).

**Collaboration** was the most frequently cited learning outcome within the teacher reflective journals, with teachers typically observing, as in the words of Molly, that students were "interested and engaged in helping each other". Collaboration was also the most frequently mentioned outcome in the teacher focus group interviews, with observations such as Abigail's: "it was really good to see them [the students] just working in groups, designing it, talking about what features they wanted". Concluding remarks in the post-implementation questionnaires showed that collaboration could take many forms, such as Penny, whose students were good at "helping each other with the app and ideas at their makers table… sharing resources, taking turns, and peer-reviewing work".

High levels of student **autonomy** and self-directed learning were noted in 13 lessons (42%) observed by researchers. Student autonomy was referenced in teacher reflective journals but came through more strongly in the teacher interviews with comments such as Abigail's: "it was incredible to see what they could figure out just by playing around with the app and then share with their peers, rather than me keeping them all together". Over half the students (n=18, 53%) mentioned autonomy in their focus group interviews, which was always in reference to how much they enjoyed having a degree of control over what they were doing and creating.

In the teacher focus group interviews, it became apparent that improved **literacy** was a major outcome of the project, being the second most frequently mentioned positive outcome in these interviews. As Amanda explained, when students "were refining their designs, the language that they used was excellent". Teachers such as Alice observed how the lessons were "rich in metalanguage and vocabulary", often as a part of giving and receiving feedback. They also explained that there appeared to be particularly strong gains for students who had historically been weaker at reading and writing, because they could engage in the language tasks in a highly applied way.

During the teacher focus groups, teachers also identified how **numeracy** and mathematical skills were intrinsically developed during the design activities, for instance with relation to 2D and 3D shapes. For example, Mackenzie described how her students "were using their social skills they use in Maths and building and creating, and I could see that they could transfer that into the design process". The student focus group interviews also revealed how students developed an applied understanding of size and proportion, with comments such as Denise's indicative of many students: "all of the things has [sic] to be the same size because if we don't move it, it's going to be like something like a blob".

Researchers observed in some classrooms how addressing scientific problems such as making a boat float, designing shadow puppets, and developing a habitat for hermit crabs could promote deep and rich **scientific understanding**. This was later affirmed in the teacher focus group interviews, for instance where Emma described how her shadow puppet task "really got us deeper into the science side of light", while Madalyn explained how developing a habitat for hermit crabs meant students could apply what they had been learning.

Students' use of technology occurred in 25 lessons (80%) observed by the research team. The development of **technical capabilities** was the second most documented positive learning outcome in teachers' reflective journals, such as when Emma explained that students gained confidence "in the initial tools I taught, which meant they were able to confidently use new tools". Students' capabilities were particularly evident in the screen recordings, where they demonstrated the capacity to create, position, resize, rotate and join the 3D objects within the Makers Empire 3D *app*. Almost half of the students interviewed discussed aspects of the 3D design process that they felt were easy. In the teacher focus group interviews, teachers articulated how students had increased their confidence in using technology.

Researchers noted the **real-world connections** being promoted through the authentic problems being addressed in 11 lessons (36%) they observed, for instance *Headphone Problem, Whose Keys are These?, What to do with an Empty Fish Tank?*, *Outspinning Mr Spinny* and *Polluting Pebbles.* In the teacher interviews, authentic learning was frequently discussed, with Emma relating that "we put up our Christmas tree… and we didn't have a star on top, and one student suggested that we should print one using the 3D printer". In the student focus group interviews, 18 students (53%) discussed connections that they had made between their designs and the real world.

The development of **communication skills** was also frequently emphasised by the teachers in their reflective journals, with one Alice arguing that her students had learned "how to give and receive feedback" and explained that her most reluctant student was now "more able to express his ideas clearly using correct terminology". The nexus between communication and collaboration emerged as a strong theme in the teacher focus groups, with comments such as Amanda's being indicative of the broader sentiment: "they were able to describe in a lot of detail what they'd change and how they'd change it and why they changed it". Teachers like Amber observed that of typically quiet students, "because they were so good at [Makers Empire], they were willing to get up and help others".

The improvements to students' **reflective thinking capabilities** were mainly evidenced in the teacher interviews, with comments such as "the main thing my students got from it [the unit of work] is that they just learned to be really good, reflective learners" (Kirsten). Reflection often followed the iterative design process and was evident in the way that students provided quality feedback to their peers. Student reflection was also raised in the teacher journals as part of class discussion, for instance that "the students were very reflective about their learning designs and were able to identify what worked, what didn't, and what they would have to do to make it work" (Ella).

**Resilience** was another theme that primarily emerged from the teacher interviews, where Ella explained that "the main thing that I loved was that they sort of found problems with their designs and they weren't really intimidated by that anymore". Ella further noted how "the kids that would just sort of give up learnt a lot more about persevering with it, and to keep trying". In the reflective journals, teachers also noted how problems that students faced, for instance with the 3D printer, developed students' resilience.

Explicitly embedded into their makerspaces units of work, **design thinking** skills were observed in the 20 lessons (65%), and the impact of this upon student design thinking capabilities is unpacked in response to the next research question.

Evidence of content knowledge development, creativity, critical thinking, problem solving, and collaboration were also observed within the student focus group interviews.

It is important to note that the learning outcomes reported here were observed across the entire study, not within each lesson, nor within every class. Whether or not these outcomes were achieved appears to very much depend on how the makerspaces module was executed. Factors predicting successful learning outcomes are further explored in the discussion of the remaining research questions below.

## 13.3 RQ2 How do maker activities using 3D technology impact on students' design thinking skills?

**Maker activities using 3D technologies resulted in students demonstrating extensive design thinking skills in discovery, interpretation, ideation, as well as varying degrees of competence with experimentation and evolution. Students also cultivated the capacity to translate their offline designs into online representations and developed a range of other 21st century skills as part of the design process.**

Design thinking was clearly evident in 20 makerspaces lessons (65%) observed by the research team. The screen recordings of student iPad activity provided a more detailed exposé of the design thinking that emerged from using the Makers Empire 3D *app*. Using the IDEO Design Thinking framework, the instances of each stage of design thinking across the 24 videos (16.5 hours) analysed are shown in Table 13.1, along with common actions and example dialogue. For more detailed explanation of the Design Thinking Phases, as well as common actions and dialogue, see Chapter 9.

Screen recordings suggested heavy emphasis on first three stages of the IDEO model (*Discovery, Interpretation* and *Ideation,* with collectively 418 coding references), with relatively limited focus on the final two stages (*Experimentation* and *Evolution,* with collectively 116 references). Both *Discovery* and *Interpretation* were strongly evident in the way students explored and interpreted the application platform through actions such as viewing, scrolling, rotating and panning objects, as well as through snippets of interpretive dialogue. *Ideation* was also strongly evident in the way that students generated multiple ideas, adding, positioning and resizing objects to represent their intended design, and very often deleting and restarting designs from scratch – sometimes with many instances in the one lesson. *Experimentation* and *Evolution* were somewhat less evident among the recorded instances that were analysed. When they did occur, *Experimentation* involved creating prototypes and fine-tuning designs through structured feedback sessions, while *Evolution* involved students meaningfully exploring the impact of their designs. While these stages were clearer in the activities observed in the lesson observations, identifying them through specific interface interactions or dialogue in the screen recordings was more difficult.

Table 13.1 – Observations of design thinking within the screen recordings

| *Design Thinking Stage* | Number of coding references | Example Actions | Example Dialogue |
|---|---|---|---|
| *Discovery* | 52 | Rotating canvas, panning/zooming canvas, browsing available objects, browsing other students' designs in the gallery | "How do you press these buttons?"<br>"How do you make a boat?"<br>"How do you make it big?"<br>"How do you change the background? |
| *Interpretation* | 147 | Discussing representation, recognising and naming objects and/or components of objects, identifying problems | "What just happened?"<br>"Now it's working again"<br>"That's a body… we need a head"<br>"I need to minus this one, so I can do that one, ok?" |
| *Ideation* | 219 | Object creation, project deletion and/or restart, object positioning, object resizing, object attachment, object colouring | "Let's do your one"<br>"Make it bigger"<br>"Turn it round"<br>"Make it green"<br>"I'm going to double this" |
| *Experimentation* | 101 | Object re-creation, object re-positioning, object re-resizing, object re-attachment, object re-colouring, object deletion | "Maybe I'll make it a bit smaller, so it can fit"<br>"Press the bomb and make it again!"<br>"I will turn the crown like this…" |
| *Evolution* | 15 | Saving objects, naming objects, presenting objects to peers | "Miss A, I'm finished!"<br>"It's called Soccer Playground, and my friend bought it". |

In their focus group discussions, 13 teachers (52%) were able to articulate both the achievements and stumbling blocks in the development of their students' design thinking skills. Teachers in this group commented on the difficulties progressing from *Ideation* to *Experimentation*. Nonetheless, in the focus group sessions, teachers seemed to recognise the IDEO Design Thinking model as a cyclical process, seeing the use of the *Makers Empire 3D* app and 3D printers as essential for supporting this process. Several teachers used poorly proportioned 3D-printed objects as an opportunity to develop students' understanding of ratios, distance and measurements, prompting these teachers to state how valuable they felt the technologies were for identifying gaps in students' knowledge and skills. In this way, the teachers helped to facilitate the *Experimentation* and *Evolution* stages with their classes, and it appeared that it was in these stages that teachers observed high levels of cognitive engagement with the design challenge.

Another key aspect that shaped and, in many cases, improved students' design thinking was the use of offline making as both parallel and sequential activities in relation to students' work with the *Makers Empire 3D* app and 3D printers. Offline making occurred in roughly half (52%) of the observed lessons, was referenced by most teachers (79%) in their reflections and was highlighted by several teachers (24%) as a key strategy in their focus group discussion. Offline designs were created using various tactile materials such as cardboard, paper plates, cups, paddle pod sticks, sticky tape and playdough. In many of the coded instances, offline-online 'translation' was arguably a challenging activity, because the process of replicating the features of an offline design in the app was not always straightforward. This prompted students to explore different tools, approaches and solutions. Similarly, an instance of less-than-successful 3D printing often prompted students to diagnose (and attempt to fix) the problems with the design before 3D printing the object again.

It is also noted that design thinking has an intimately-interconnected relationship with other capabilities observed in this study – namely, creativity, problem solving, critical thinking, inquiry, collaboration, autonomy, literacy, numeracy, scientific understanding, technological capabilities, communication, reflective thinking and resilience. It is through design thinking tasks that all of these skills have been developed, and design thinking requires all of these capabilities. To this extent, design thinking is such an important capability because it utilises and develops all other 21st century capabilities.

## 13.4 RQ3 What supports and constrains learning in maker activities?

**Learning in makerspaces is affected by the balance of explicit instruction to open-ended inquiry, the general pedagogical strategies that are used, the types of tasks that are set, the effectiveness of technological resources that are used, the sequencing of tasks, the design of the spaces being used, students' background knowledge, and their ability to collaborate productively. Each of these factors were observed to support or constrain learning, depending on how they were configured.**

Teacher practice was fundamental in supporting or constraining learning in makerspaces. The lesson observations highlighted the need for a balance of explicit instruction and open-ended inquiry within the makerspaces lessons. For example, observations of highly explicit lessons suggested that prescribed (and relatively simple) tasks could provide students with a clear and concrete understanding of how to use the app and the design process but constrain opportunities for students to develop higher-order knowledge and skills. Alternatively, more open-ended tasks enabled learners to develop their creativity, problem solving and critical thinking capabilities, but in situations where instructions and/or modelling were less explicit, some students struggled with the tasks and made limited progress. Some teachers appeared to have an intuitive understanding of this, with 24 lessons (77%) observed involving explicit instruction and 17 lessons (55%) incorporating open ended inquiry. In their reflective journals most teachers emphasised the importance of explicit instruction (79%) and open-ended inquiry (63%), and the need to balance them according to the learning requirements of students.

In their journal reflections, teachers also documented several other pedagogical approaches that they felt could support learning, including teacher modelling, group work, peer feedback, targeted questioning, class discussion, provision of scaffolding, reinforcement and revision, and providing adequate time to properly facilitate inquiry learning. Interestingly, in the professional learning workshops teachers were already identifying pedagogical tactics to support learning, including having help posters for common troubleshooting issues, encouraging a learning environment where failure was valued as potentially being productive, and providing students with adequate time with the tools before applying them to specific design projects.

The impact that the nature of the task had upon learning was also clear in the lesson observations. Tasks varied in terms of real-world applicability, authenticity, focus, and predictability, and as one teacher aptly expressed in her reflective journal, teachers were often "struggling to find the problem". Some problems were relatively straightforward and easy to solve – such as designing herb markers to correctly identify herbs in the garden – leading some students to finishing their work early, restart the same design without much further development, and in some cases deviating to off-task activity. By contrast, problems that were more complex and difficult to solve – such as designing a key ring that reflects the interests and cultural background of the wearer – often led to sustained efforts over the course of several lessons, and to more sophisticated designs. Researchers observed that it was also important for teachers to help students understand the relevance and meaningfulness of the task they were completing by making explicit links to real-world applications.

Across the data, technology was seen as both supportive and constraining of learning in makerspaces. For instance, the *Makers Empire 3D* app was fundamental to each unit of work, and was the means through which discovery, interpretation, ideation, experimentation, evolution, and other 21st century learning processes took place. The screen recordings evidenced literally hundreds of instances where students were successfully creating, positioning, rotating, resizing and attaching objects in the 3D platform, as part of their design processes. Teachers reflected that the application and development of design thinking capabilities and the ability to critically refine designs, with Amanda commenting, for instance, that this kind of critical thinking “may not have had [achieved] without the support of the app”. The app also enabled students to explore their peers’ designs, and in many cases, students chose to use the app outside school and to make their own personal creations.

However, students and teachers also pointed out some difficulties learning and working with the app. In their interviews students described difficulties raising, lowering, positioning, rotating, attaching and resizing objects. Teachers’ commentary during the professional learning program reflected their difficulties working with the *Makers Empire 3D* app for the first time. When prompted, teachers were able to suggest ways to make the app easier to use for their students to use, and how to avoid issues like distraction and cognitive overload. For example, some teachers recognised ahead of time that the token system and avatar customisation pages could prove distractions for their students, and this was subsequently evident in the video recordings that the research team analysed. Several teachers also were concerned about the difficulties young learners – especially those in Kindergarten – would face, given the literacy challenge of reading tutorials and in-app feedback. These concerns likewise persisted throughout the study as perceived constraining factors.

In their focus group discussions, teachers recognised 3D printing as both a supporting and constraining factor in maker activities. Teachers agreed that 3D printers were an essential element in celebrating their students’ successful 3D design attempts. However, focus group data revealed that ten teachers (40%) were frustrated with 3D printing, citing the malfunctioning of some printers and speed at which all printers were able to print completed designs. On the other hand, instances of less-than-successful 3D printing often prompted students to diagnose and attempt to fix the problems with the design before 3D printing the object again, thus promoting problem solving and perseverance.

The post-implementation questionnaire data suggested that teachers viewed some technology resource issues as both supportive and constraining, where both “problems with technology in the school” and “resources” drew the largest number of references, with 17 teachers (63%) commenting on each. As the two main resources in much demand, sufficient iPads and reliable internet connectivity were frequently cited as the main supporting elements needed to conduct the online lessons successfully. But these supports quickly turned into constraining factors whenever problems were encountered, such as when Abigail conceded the biggest difficulties “we faced were the technology and printer problems that stopped us from being able to print the designs that students made”. Even late in their involvement in the study, a sizable portion of teachers (44.4%) reinforced their need for collegial support – and especially IT support – to help solve problems, especially with connectivity and 3D printing.

Continuity and sequencing also impacted upon learning. The lesson observations underscored how students' designs could be successfully sustained, iterated, improved and critiqued over the course of the unit of work, in accordance with the IDEO *Design Thinking for Educators* model. However, the lessons and screen recordings examined revealed the prevalence of self-contained design lessons, where students started and finished individual designs from scratch, rather than working on a design over the course of several lessons. Even more striking was the tendency of many students to delete their work and start again several times in one session, as observed in some of the screen recordings. This approach constrained the amount that they could learn from critical reflection and iterative refinement. While offline making activities were a common strategy that teachers used to support the design processes of students (as noted in response to the previous research question), sometimes students would undertake offline design after the online design if no iPads were available. Therefore, while offline tasks could support learning, resourcing issues sometimes meant that students were merely recreating what they had produced online rather than prototyping what they wanted to produce online.

Space configuration was also an area of interest in the focus group discussions, with 11 teachers (44%) believing that a well-configured space was important to support better learning. Most teachers seemed to agree that a space with fixed resources was far better than having mobile resources where, as Alice argues, teachers needed to "go packing and unpacking" from one class to the next. Several teachers were also very positive about purpose-built spaces, such as outdoor makerspaces, which in Ella's words "really informed the Science concepts… [and] gave them a lot more context and understanding about what they have to then put into that [their designs]". In a classroom setting, many teachers felt that flexible furniture was – or would be – a huge benefit for supporting maker activities, particularly in enabling students to work in different group configurations and allowing both offline and online maker activities in the same lesson. Although one group of teachers had decided to combine their three classes into one open-plan makerspace, noise levels, inflexible furniture, and difficult-to-solve connection issues meant that they felt large, open-plan makerspace lessons were far more constraining than supportive of the learning they wanted their students to achieve.

As part of their reflective journals, teachers also identified how student misconceptions and background knowledge could constrain learning. For instance, students often had misconceptions about what could and could not be 3D-printed. As well, lack of curriculum knowledge about ratios and measurement, and challenges reading in-app text, could constrain their design thinking processes. Also, insufficient knowledge about how to go about design itself, for example, deconstruct the problem, could limit student learning. During the screen recordings one Kindergarten student concedes, "I really don't know how to make a boat".

Genuine collaboration was observed to advance outcomes in 14 of the 31 lesson observations (45%), through the exchange of ideas and skill sets. The screen recording case study with Charlotte and Polly (Chapter 8) demonstrate how students could benefit from collaborative ideation and interpretation. Collaboration was a frequently mentioned positive outcome in the reflective journals (63% of teachers). Teacher responses to the focus group interviews and post-implementation questionnaires both strongly emphasised improvement in students' collaborative skills as a positive outcome of the makerspaces modules. However, researchers observed several instances children struggled to share the iPads with their peers or could not reach consensus about what or how to design. Other observations from teacher reflective journals revealed instances of a more dominant child constraining the learning of their peers. Students identified that group work could be a problem if team members weren't working well. Thus, group work can either contribute to, or detriment learning, highlighting another important factor for teachers to consider.

## 13.5 RQ4 How do maker activities using 3D technology influence student motivation, engagement, self-efficacy and future intentions?

**Maker activities using 3D technology resulted in very high levels of learner engagement, as well as marked increases to some students' confidence – particularly those less capable students. Off-task behaviour was sometimes observed to result from unavailability of technology resources, students' developing abilities to work productively in groups, and gamification aspects of the software. There was strong student demand to undertake further lessons involving 3D design and printing, with many students expressing a desire to engage in 3D design activities outside school, and in their future careers.**

High levels of student engagement were documented in all 31 of the lessons observed by the research team. In the 24 screen recordings, similar levels of student excitement were coded in 83 separate instances, such as when they discovered new design possibilities or were successful in creating their intended design. In their interviews, several students expressed enthusiasm about the *Makers Empire 3D* app itself, giving it ratings such as "100%" or "eleven out of ten". Students recognised that their enjoyment stemmed from the ability and to create, the challenges they completed, and the game elements of the system. Students expressed enjoyment in being offered the freedom to choose what they designed. Several students also commented that Makers Empire had increased how much they like school.

Enthusiasm was independently referenced as a positive outcome by 22 teachers (92%) in their reflective journals, and engagement was identified as a positive outcome by 18 teachers (75%). They indicated a range of intrinsic sources of enthusiasm, including finding out how to do something new using the *Makers Empire 3D* app, or successfully designing an object. Some teachers expressed how much students enjoyed the collaborative aspects of designing together and sharing their ideas. Teachers also commented how much students enjoyed tactile aspects of the project, for instance how much they "love starting to see some of their creations being printed out", or how much they liked the offline making activities.

Several causes of off-task behaviour were evident in the screen recordings. Some of these related to the design process, such as not being able to operate the interface as desired (e.g. resize objects), or not understanding how to complete the task. In many instances, students were distracted by aspects of the app itself, for instance, level-up notifications. Across the screen recordings, there were 26 "level up" notifications observed, which usually prompted students to leave their designs and interact with the avatar or shopping features of the platform. This was often the cause of the 40 coded instances of off-task behaviour. Additionally, sometimes students would browse the gallery or enhance their avatar in ways that bore no relation to the lesson. Once distracted, it was possible for some students to be observed in off-task behaviour for sometimes lengthy periods. Because these students appeared highly engaged with the app, it was often difficult to detect that students were off-task. Semi off-task behaviour could also be observed when students spent considerable time colouring components within a design, even though these colours would not translate to the immediately 3D-printed object. In their reflective journals, teachers sometimes observed how student engagement could also be adversely affected by their ability to work harmoniously with peers, for instance collaborate on a task, ask questions of each other, and share the equipment. Engagement could also be negatively impacted by the availability of iPads for students to use.

Increases to students' confidence were frequently reported in the teacher interviews. Several teachers indicated that confidence essentially came from being able to design and build in the *Makers Empire 3D* app. Confidence manifested itself in many ways, including the ability to "go and do that [task] independently", or where students would "run around and show the others", or in the form of greater comfort and capability using the technology. A recurring theme in teachers' interviews was the particularly positive effect that the project had on weaker students, who were reported to "thrive using the app". For instance, Dawn's "lower ability kids' confidence improved a lot, and they came up with fantastic, exciting ideas". Penny described one student in her class that was now "absolutely busting to answer questions... and just eloquently put it [the answer] into these sentences that I've not heard him speak before". One of Julia's previously reluctant writers is now "a shining star". However, Tim expressed concern that some students in his class – especially girls – "withdrew at the end of the lesson… students who had a louder voice would just lead the whole thing, and the girls would do their own thing".

In their interviews students also indicated positive intentions towards using the *Makers Empire 3D* app in future. All 34 students (100%) expressed a desire for further lessons involving 3D design and printing using Makers Empire. Six students (25%) had already installed the *Makers Empire 3D* app on a home device and were actively creating, often with other family members. Additionally, a broader poll of students at the largest participating school indicated that 242 out of 249 students (97%) would like to do another unit of work on 3D design and printing using the *Makers Empire 3D* app.

Of the students interviewed, there were 32 (92%) who expressed an interest in pursuing 'making' post school. In some cases, this manifested as a desire to make practical day-to-day objects such as buildings, clothing, jewellery and toys (like a "toy ball for my dog"). In other cases, students conveyed grand visions of what they might create, with six (19%) further explaining how their designs might solve current and future social problems, for instance producing "a really big house… so lots of people can live there".

## 13.6 RQ5 How can teacher capacity to embed design thinking processes through maker-based pedagogies be developed through a blended professional learning program?

**Involving face-to-face workshops and online support, the professional learning program led to a significant increase in teacher confidence to teach in makerspaces. Teachers indicated that the well-structured, pedagogically grounded, hands-on and situated approach teachers having a better understanding of makerspaces, how to teach in them, the technical skills required, and 21st century capabilities more generally. Prioritising time to master the technology and repositioning the online professional learning as more responsive to teacher needs are potential strategies going forward.**

Researchers observed numerous meritorious aspects of the blended professional learning program that was offered to teachers. The face-to-face workshops provided the teachers with strong pedagogical foundations for their practice, based in constructivism and constructionism. The coverage of the IDEO Design Thinking model meant that teachers had a framework for the problem-based pedagogies emphasised by contemporary curriculum. The workshops also introduced participants to the technology combination of 3D design software and hardware, making a case for how these technologies could be used to enact both curriculum and pedagogy. The sessions modelled the sorts of pedagogies being discussed through an appropriate mix of instruction and hands-on interactive activities. Teachers were provided with time to practise design thinking and relate what they had learnt to their own classes and curriculum context. The facilitator quickly developed rapport with the participants and was able to elicit ongoing involvement and enthusiasm.

The online professional learning in the form of the Edmodo social networking site and the Zoom web-conferencing sessions afforded advantages to participants. However, it was interesting to note that the online professional learning support was mainly utilised by more experienced teachers with lower technology confidence. The Edmodo page allowed teachers to openly discuss the problems they were experiencing (including technical issues), and for the facilitator to communicate with all participants at once. The facilitator's discussion topics received some responses from participants in the first three weeks but none in the last week, perhaps due to teacher busyness.

There were some relatively minor suggestions for improving the professional learning. Given the difficulties some teachers faced when forming a problem to be framed as a design challenge, one researcher observed that there could have arguably been more emphasis on the IDEO model to ensure that teachers developed a robust understanding of how to embed necessary design thinking processes in their planning. Additionally, another researcher observed that the facilitator could have been more insistent that participants watch technical demonstrations (i.e. put down their iPad) so that they could acquire essential techniques. While the online professional learning support appeared to be utilised by the teachers with more years of teaching experience and lower levels of technological confidence, it may have been possible to put in place supports and extensions for more experienced and tech-savvy teachers. Finally, one researcher observed that it may have been possible for the facilitator to more closely apply the highly relational and interactive approach of the face-to-face sessions in the online sessions.

In the post-professional learning questionnaire, the teachers indicated that the professional learning was well designed (average score of 4.6 out of 6, between 'mildly agree' and 'agree'). Teacher confidence to teach in makerspaces increased from a mean of 3.04 (approximately neutral) in the pre-professional learning questionnaire to a mean of 4.44 (between mildly agree and agree) in the post-professional learning questionnaire. This was a highly significant result $t(26)=4.875$, $p=0.001$. Likewise, the statistically significant increase in confidence to teach in makerspaces appeared to be of most benefit to teachers with initially low or very low technological confidence, whose confidence teaching in makerspaces progressed from M=2.63 to M=4.38. There was a dip in enthusiasm to teach in makerspaces from a pre-professional learning questionnaire mean of 5.22 (between agree and strongly agree) to a post-professional learning mean of 4.78 (between mildly agree and agree). This change in enthusiasm was not significant and may have been due to the greater awareness about the work involved in preparing for their makerspaces lessons, or the timing of the final day of professional learning (last week of term).

Teachers identified several positive outcomes of the professional learning in their responses to the post-professional learning questionnaire. Most teachers (n=16, 59%) explicitly commented on how the professional learning had increased their confidence, with comments such as they "can use 3D technology to further enhance children's thinking". Many teachers (n=11, 41%) also reported a greater understanding of makerspaces and their benefits, for instance through "guidelines for teachers to introduce it to their children". Seven teachers (26%) commented on how their understanding of maker pedagogies had improved, for example with a teacher explaining that she had "not looked carefully at it [design thinking] before, other than in the context of Project-Based Learning". Some teachers (n=5, 19%) spontaneously mentioned the value of having time to collaboratively plan and develop units of work as highly valued, with one teacher identified the primary benefit of the program as "being able to collaborate with colleagues on how to use this technology in specific units of work". Eleven teachers (41%) commented how the program had helped them to develop their 21st century capabilities, for instance their ability to "looking at problem solving in a new way". Eight teachers (30%) also commented on how their technical skills had improved.

In terms of suggestions for the professional learning program, nine teachers (33%) expressed an appreciation of the "hands on" and "experiential" learning, with some of these teachers indicating more time with the hardware and software would be beneficial. Some teachers (n=4, 15%) felt that the online professional learning was less valuable than the face-to-face sessions, with Nadia commenting that she was "not confident in accessing the notes online, felt a little panicked to complete in between tasks, [and] not all sessions were relevant to getting the project started". Six teachers (22%) suggested more support with the app in terms of "more detailed instructions on how to use the Makers Empire 3D app" and "a little more support when the tech was not working".

## 13.7 RQ6 How can teachers be best supported to develop their maker pedagogical capabilities?

**For teachers to effectively develop their maker pedagogical capabilities, they need to be provided with access to reliable technology, collegial support, teaching resources, appropriate makerspaces, and time to develop their capabilities and lessons. In addition, they are best supported by a school culture that encourages exploration and experimentation.**

In the post-implementation questionnaire, teachers provided a clear indication of the external factors that were required to support their makerspaces lessons. There were 17 teachers (63%) who raised problems with technology in the school, including insufficient iPads, the app not working on older iPads, poor access to Wi-Fi, and 3D printing problems. For teachers to develop their maker pedagogies, they need to have a robust and fully functioning suite of technologies with which to practise. In addition, teachers raised the need for appropriate physical spaces for offline making tasks, including materials and storage. Twelve teachers (44.4%) raised the importance of collegial support in their responses, agreeing that it contributed positively to their professional learning. The main reason for desiring collegial support was for incidental technical assistance, though other reasons included for lesson ideas and to exchange teaching strategies. Five of the teachers (15%) explicitly mentioned time as a factor required to develop their pedagogical practices, for instance to plan lessons and instruction, but also at the implementation phase so teachers did not feel rushed.

Interestingly, the themes of functioning technology, resources, collegial support, and time were all identified in the pre-professional learning and the post-professional learning questionnaire, with varying emphases. This indicates that teachers generally had an accurate idea of the supports they needed at the outset of the project, and accurately predicted the problems they would face. By the end of the project, teachers felt less of a need for resources in the form of lesson plans and models, and a greater need for the actual tactile resources and spaces that they and students could use in their lessons.

The importance of adequate time was also particularly evident in teacher journal reflections, with nine teachers (37.5%) clearly indicating a preference for more time exploring and playing with the app. In other words, teachers recognised, as Jenna stated, the need "to have a play around with the app myself", and the value of exploratory learning for developing their own maker pedagogical capabilities. This speaks to the values that many teachers identified and idealised in the professional learning when exploring Papert's (1986) theory of constructionism. This is especially true of the "eight big ideas" that the facilitator shared during the first day: *learning by doing, building with technology, hard fun, learning to learn, taking time, failing well, teachers as learners* and *learning together*. These ideas collectively encouraged teachers to think of themselves as learners, and to allow ample time and opportunity to experiment with the technologies and design process, to make mistakes and to collaborate with colleagues. This form of learning sits at odds with the limited and results-driven time that teachers typically have – as one teacher notes in the face-to-face program, "a school culture of not making mistakes", and it is this same tension that underpins many teachers' reflections.

The teacher focus group data underscored the need for support to be flexible enough to allow for the "feel your way as you go" approach that many teachers embraced in the implementation of their units of work, with increased collaborative planning (n=4, 16%) and greater flexibility (n=5, 20%) emerging as areas of teacher transformation. Teachers readily described their unit implementation as an organic process of feeling their way, trial an error, and just-in-time learning. They enjoyed working with their colleagues, combining ideas to develop units of work, and supporting, inspiring and encouraging one other when needed. Some teachers used the word "journey" to describe their development throughout the study. Critically, this often included a change in thinking, with many teachers explaining how they needed to let go of previously-held beliefs, and particularly let go of different conceptions of "control" in their teaching practice, or as Sophie remarks, allowing "the unit to progress as it did, given whatever circumstances were defining it, and then allowing us more input into how it went". Several teachers (n=7, 28%) also heavily referenced teacher-learner partnerships as something particularly important to developing their maker pedagogical capabilities, where, as Jenna points out, "the kids were teaching me at some points". For most in this group, these partnerships involved the teachers learning from the students, seeing themselves as learners, and not being afraid to ask for help from students or their colleagues. Elsewhere in the data, there are emphases peer mentoring, problem-based learning, project-based learning, and inquiry – all of which speak to the kinds of pedagogical change that teachers experienced.

The post-implementation questionnaire data revealed significant improvements to confidence, enthusiasm and maker identity. Figure 13.1 shows the changes in the mean response to the items for confidence and enthusiasm. As shown, the item with the largest change was confidence, which increased significantly from pre-professional learning levels, $t(26)=7.29$, $p=0.000$, and then enthusiasm (which dipped slightly from pre- to post-PL and then rebounded significantly, $t(26)=2.55$, $p=0.017$.

Moreover, there was a significant increase in teachers identifying with being a maker following the implementation period, as well as increased agreement with the importance of makerspaces for learning, as measured in both pre-professional learning and post-implementation questionnaires. These two variables are shown in Table 13.2 and graphically represented in Figure 13.2.

Table 13.2 – Confidence, enthusiasm, maker identity and maker values (pre-PL and post-implementation)

| | **Pre-Professional Learning Questionnaire** | | **Post-Implementation Questionnaire** | | **t** | **df** | **Sig (2-tailed)** |
|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | | | |
| *1. It is important for students to acquire maker learning capabilities* | 5.0 | .73 | 5.37 | .74 | 1.91 | 26 | .067 |
| *2. I feel confident to teach in makerspaces* | 3.04 | 1.16 | 5.0 | .62 | 7.29 | 26 | .000 |
| *3. I feel enthusiastic about teaching in makerspaces* | 5.22 | .75 | 5.56 | .58 | 2.55 | 26 | .017 |
| *4. I see myself as a 'maker'* | 4.07 | 1.07 | 5.0 | .83 | 4.22 | 26 | .000 |

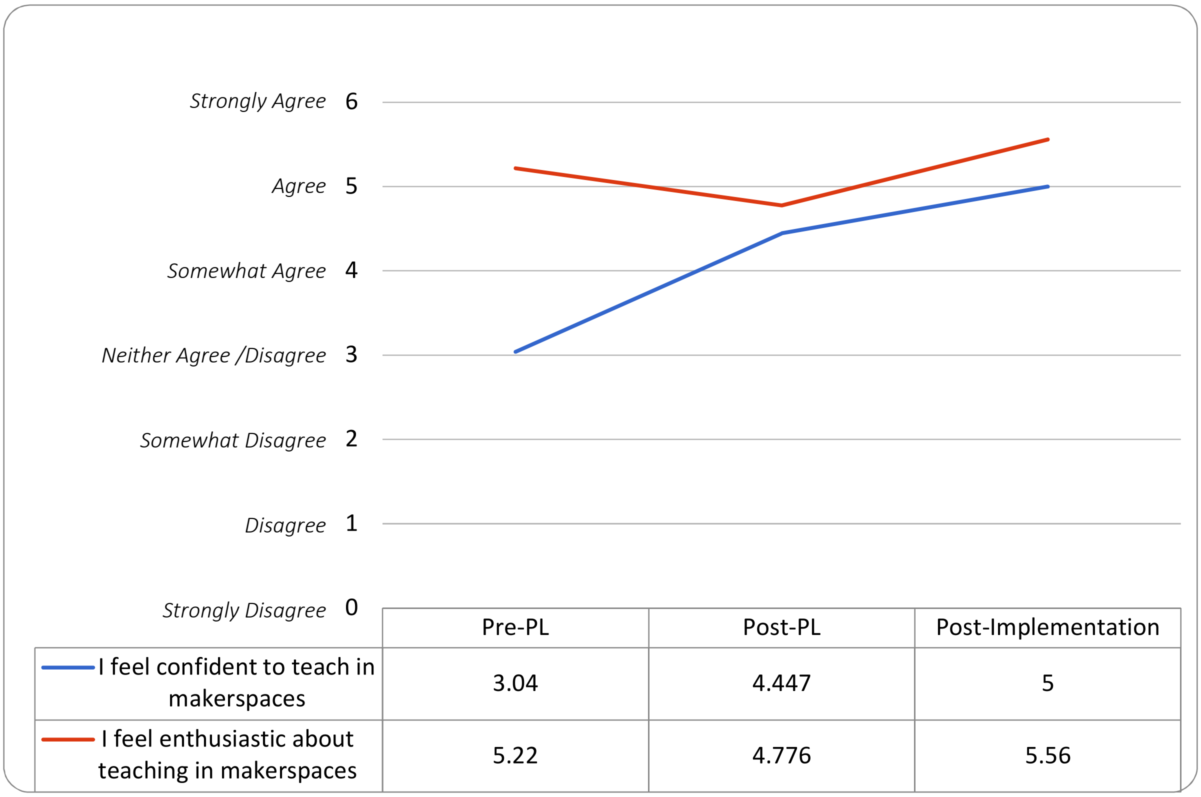
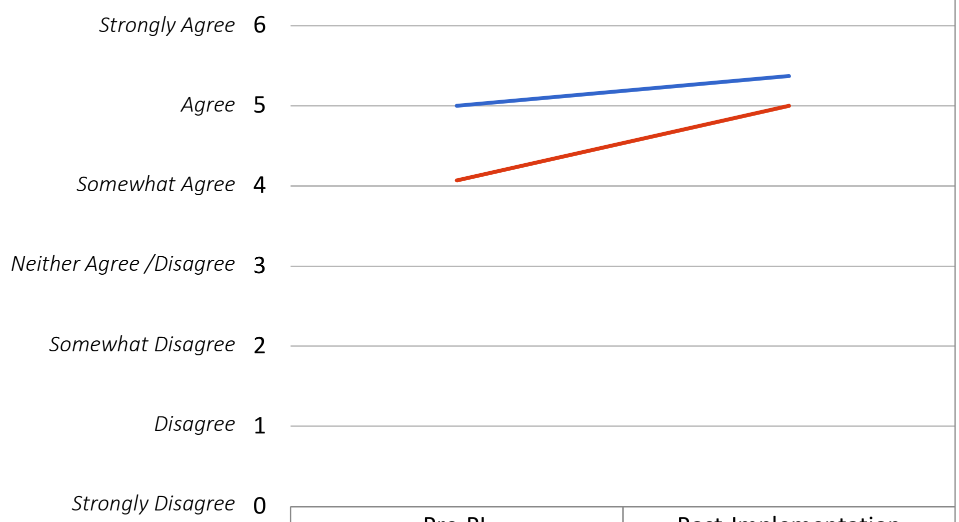



Figure 13.1 – Confidence and Enthusiasm for Teaching in Makerspaces (Pre-PL, Post-PL and Post-Implementation)




| | Pre-PL | Post-Implementation |
|---|---|---|
| It is important for students to acquire maker learning capabilities | 5 | 5.37 |
| I see myself as a 'maker' | 4.07 | 5 |

Figure 13.2 – Importance of Makerspaces and Maker Identity (Pre-PL and Post-Implementation)

These results also raise important questions about the bounds of professional learning and what is really required for teachers to develop their maker pedagogies. While the structured professional learning was of critical importance for improving teachers' confidence to a level where they were comfortable to embark on their makerspaces modules, the reflective journals, lesson observations and teacher focus groups show that it was largely by practising maker pedagogies in their actual classes that teachers' confidence, enthusiasm and maker identity improved. Similarly, teachers' knowledge of makerspaces and pedagogical strategies were observed to substantially evolve from the pre-professional learning to the post-implementation, as a result of teachers' hands-on experiences. To that extent, the entire project was a process of continuous professional learning – both formally-structured and informal – for the teachers involved.

## 13.8 Limitations

Like any research, there are limitations to the findings presented in this study. The findings are drawn from one sample that was heavily dependent on the school contexts, teachers, students, professional learning, and technologies. Rich descriptions have been provided throughout this report so that the transferability of results to other contexts can be evaluated.

# 14 Concluding Comments and Future Considerations

*As a result of the analysis conducted in this study, future considerations are proposed, including that i) the expansion of makerspaces in the primary school system is support, ii) teachers carefully consider the balance of pedagogies, tasks, sequencing, space design student prerequisite knowledge and groupwork management, iii) teachers are offered extensive professional learning to support makerspaces integration, iv) that professional learning continues to be hands-on, collaborative, pedagogically grounded, as well as enabling extensive exploration of technologies and being responsive to individual needs, v) strategies be put in place to address potential accessibility and distraction issues associated with the use of the 3D design software by young children, vi) that schools take active steps to support makerspace-based learning, vii) that teachers be offered adequate time to design and implement their makerspace units of work, viii) that communities of practice be developed and supported relating to makerspaces pedagogy, and ix) that further research be conducted into how teachers can effectively mentor and lead each other throughout educational systems to enhance makerspace-based learning. The significant changes to professional practice that occurred because of the project are highlighted as an unanticipated outcome.*

## 14.1 Reflections on the Study

The pedagogical approaches observed in this study developed students' STEM competencies, 21st century skills, and digital capabilities, directly responding to calls from government and industry (Australian Industry Group, 2017; Deloitte Access Economics, 2014; Education Council, 2015; Innovation and Science Australia, 2017; Kaspura, 2017; P21, 2009; PwC, 2015). The study also responds to the observed paucity of research that examines pedagogical aspects of makerspace-based learning in the younger years, using in-depth and cross-case analysis. Transformation was affected through professional learning that focused on long term change, design thinking, and supporting teachers to undertake individual inquiries, as recommended in the makerspaces professional learning literature (Bowler, 2014; Harron & Hughes, 2018; Oliver, 2016b). While the multiple data sources and analytic techniques used in this study has enabled the research team to confidently respond to the *a priori* research questions, there were also some interesting additional findings with relation to teacher practice and their conceptions of makerspaces.

One anticipated finding of the study was the extensive **teacher change** that occurred in many cases. Teachers identified how the shift to teaching in makerspaces led them to become more collegial and collaborative (" [it was] like the children, collaboration and working with a colleague … we inspired each other to take the risk"). Teachers noticed how their teaching became more flexible ("a lot of trial and error… [where] we'd start doing one thing, and then I'd realise they needed a lot more background knowledge"). Some teachers indicated how the project had enabled them to become more comfortable with technology ("I'm not scared of technology… and it's made me want to look into it more"). The classroom shifted to an environment where teachers were in a learning partnership with students ("step back a little bit and actually let [students] learn through discovery… and show me other things that I didn't know"). As a consequence, students were able to see their teachers modelling life-long learning dispositions ("it's nice for the kids to see us learning… and one of my girls said the other day,' oh, you never stop learning all your life'").

Several teachers explained how participation in the project had led to them changing their pedagogical practices more broadly ("I have changed my teaching practice to incorporate more problem based learning styled lessons and programs"), and their attitudes towards teaching ("I have learned to trust more in the kids, [because] they really do rise to a challenge, and they exceeded my expectations in their creations"). In some cases this was evidently a consequence of being challenged to adopt a more flexible and inquiry-oriented approach to teaching ("little groups would come and work on it [the task] together… and I found that I was like 'Whoa – this is the way to teach!'… so this is working"). Teachers realisation of how the project had transformed their practice, and the impact that it had on students, may have been behind all 24 teachers (100%) indicating that if given free choice they would like to use Makers Empire again to facilitate 3D design and printing activities in their classes.

Another interesting finding of the study was the more **in-depth understanding of makerspaces** that teachers cultivated as a result of the project. In both the pre-professional learning and post-implementation questionnaires the teachers identified makerspaces as linking to curriculum and requiring certain sorts of more inquiry driven pedagogies. However, in the post-implementation questionnaire teachers placed much more emphasis on the physical aspects of makerspaces (21 references) as compared to the pre-implementation questionnaire (6 references). For instance, Ella describes them as "creative, open-ended design spaces for solving real life problems" and Madalyn explains them as "spaces for students to put their design thinking into action, where they can collaborate, investigate, design, make, test, evaluate and redesign and reflect". The greater emphasis on the physicality of makerspaces may be a result of the actual concrete and hands-on experience that teachers had garnered through teaching in makerspace-based settings. In addition, teachers concentrated less on the technological aspects of makerspaces in the post-implementation questionnaire (2 references) as compared to the pre-professional learning questionnaire (7 references). This could be interpreted as an indication that the technology had become more intrinsically integrated into teacher practice, rather than being seen as a separate entity.

Throughout the study there were several other themes and issues relating to student and teacher learning, that were not directly incorporated into the reporting of findings. For the purposes of brevity these are not listed here, however, interested readers are referred to the individual analysis chapters for more in-depth and nuanced results across the range of data sets.

## 14.2 Future Considerations

The analysis of the multiple data sources across a collection of cases naturally raised several issues with relation to learning and teaching in makerspaces. As a result of the analysis and findings in this study, the following future considerations are tendered.

1. **That support be provided to promote makerspaces in schools as an effective and integrated means of developing STEM skills, digital competencies, and** 21st century **learning capabilities.**

This study has demonstrated that makerspace-based activities provide a context for primary school students, even from very early years, to learn creativity, problem solving, critical thinking, inquiry, design thinking, collaboration, autonomy, literacy, numeracy, scientific understanding, digital literacies, communication, reflective learning and resilience. The study also indicated high levels of student engagement, enthusiasm, and motivation to continue with 3D design and printing activities beyond the classroom and even as part of a future career. Given the increasing national and international emphasis on developing 21st century capabilities, and the positive influence upon motivation and future intentions, every child should have access to makerspace-based learning opportunities from the earliest years of schooling.

2. **That teachers who are implementing makerspaces modules are encouraged to strike a balance between explicit instruction and open-ended inquiry, set authentic tasks that are appropriately problematised, sequence tasks constructively, consider the design of their teaching spaces, attend to students' prerequisite knowledge, and actively guide group work processes.**

Several findings from the teacher interviews, teacher reflective journals, lesson observations and screen recordings informed the pedagogical approaches that support learning and teaching in makerspaces. A balance of explicit instruction and open-ended inquiry provided students with the background knowledge that they needed as well as the opportunity to develop their independent investigatory skills. General pedagogical strategies such as teacher modelling, peer feedback, targeted questioning, class discussion, group work, provision of scaffolding, reinforcement and revision, and providing adequate time to properly facilitate inquiry learning were also found to be helpful. Authentic tasks that were focused on solving a specific but sufficiently challenging problem appeared to promote engagement and learning. Constructive sequencing of tasks rather independent or regressive tasks meant that students could incrementally build their capabilities. Having necessary equipment available and a space that supported flexible configuration assisted makerspaces learning. The required background knowledge in terms of the task, the technology, and what can be realistically created, supported students to successfully construct their final products. Group dynamics and the ability of students to work with their peers influenced learning, with teacher guidance in this respect able to support learning outcomes.

3. **That co-ordinated professional learning opportunities be provided to teachers to improve their knowledge of design-based learning and how makerspaces curriculum can support its development.**

Results show that teaching in makerspaces is a complex undertaking, which in many cases involved teachers shifting from more instructive approaches to more flexible, collaborative and inquiry-oriented pedagogies. Designing good tasks, acquiring prerequisite technological capabilities, and developing confidence to teach in makerspaces are all most efficiently cultivated with ongoing support. The professional learning program in this study was instrumental in equipping teachers with the design, technical and pedagogical knowledge they needed, as well as significantly improving their confidence prior to implementing makerspaces modules in their classes.

4. **That the professional learning opportunities provided to teachers is well structured, pedagogically grounded, hands-on and collaborative, incorporating extensive opportunities to explore new technologies and being responsive to individual contexts.**

Teachers in this study valued the well-structured, pedagogically grounded, hands-on and situated professional learning that was offered. Teachers also indicated that they would like more opportunity to master the technology and would prefer any online professional learning support to be tailored to their individual needs as far as possible.

5. **That strategies be applied to address potential accessibility and distraction issues associated with the use of the 3D design software by young children.**

While the 3D design and printing software that was used in this study was fundamental to developing students design thinking and 21$^{st}$ century capabilities, and was favourably viewed by almost all participating students, some issues were observed relating to its use by younger students with potentially low literacy and dexterity levels. Accordingly, teachers may choose to provide language and interpretation support to students with low levels of literacy, as well as using the manipulation of the interface as explicit and deliberate motor tasks. As well, the gamification aspects of the platform were observed to impede classroom learning in some instances. As such, teachers are encouraged to be proactive about managing the possibility that gamification interferes with classroom learning goals, and to be vigilant about monitoring student activity. Further refinement of the interface to take advantage of device accessibility features and reduce the possibility of distraction would be helpful.

6. **Schools take affirmative and comprehensive steps to provide the resources, spaces, and culture that support makerspace-based learning.**

In order to undertake the 3D design and printing activities it was first necessary to have at least one fully-operational tablet device for every two students, a strong Wi-Fi connection with unencumbered Internet access, numerous 3D Printers, and access to technical support. It was also important to have designated and purpose-built makerspaces as well as streamlined access to materials and equipment in order for students to invent and create. A school culture that supports exploration and experimentation, through the provision of resources as well as through valuing productive failure, is also fundamental to encourage successful maker-based learning.

7. **Schools apply strategies to provide teachers with time to design and implement their makerspace-based lessons.**

Teachers need time to engage in the experimental and exploratory learning that is required for them to develop their own makerspace-based capabilities and pedagogies. Additionally, in a crowded curriculum, and in recognition that makerspace-based learning can be used to achieve a range of curriculum and general capabilities, appropriate timetable accommodations need to be made for students to undertake genuine inquiry learning as part of makerspace-based units of work.

8. **School are encouraged to share and collaborate to build Maker expertise amongst staff, engaging parents and other community stakeholders in forming makerspaces communities of practice.**

Teachers observed that professional support was imperative so that they could generate ideas, share strategies, and provide one another with trouble-shooting assistance. Schools and systems can play an important role in forming, resourcing and promoting communities of practice focused on makerspace-based learning.

9. **Further research to determine effective systems through which makerspace leadership capabilities can be developed and propagated within and between schools.**

How to effectively scale up systemic capacity from pilot programs is an endemic educational problem. In light of the strong demand to build STEM capabilities of school students and the corresponding pedagogical capabilities of their teachers, an investigation of the factors that support and constrain in-school mentorship and between-school leadership in the makerspaces area could lead to research findings that increase the effectiveness with which STEM capacity is generated. This could also cultivate insights into how to enhance intra-system professional development more generally.

## 14.3 Final Remarks

It has been a privilege to be a part of this innovative and fascinating project. The research team would like to acknowledge that this study would not have been possible without the willing and generous cooperation of the teachers and students from Carlingford West Public School, Parramatta East Public School, and Oatlands Public School. We thank them for their kind and inspiring contributions.

Finally, it is intended that the findings from the Makerspaces in Primary School Settings project provides teachers and schools internationally with an evidence base to effectively implement makerspaces-oriented 3D design and printing activities in their classes. We hope that this project marks the beginning, rather than the end, of investigations into how makerspace-based 3D design and printing can be used to enhance outcomes for students and teachers. We welcome external feedback and correspondence in this respect.

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# 16 Appendices

## 16.1 Appendix 1: Pre-Professional Learning Questionnaire

Q1 (Text) Welcome to the Makerspaces project. As part of the research component of this project we would like to understand a little bit about your prior knowledge and thoughts. Please take the time to carefully answer the following questions.

Q2 Name:

Q3 Age

- ○ 20-24
- ○ 25-29
- ○ 30-34
- ○ 35-39
- ○ 40-44
- ○ 45-49
- ○ 50-54
- ○ 55-59
- ○ 60-64
- ○ 65+

Q4 Years of teaching experience (whole years):

Q5 How would you rate your confidence in teaching with technology?

- ○ Very Low

○ Low

○ Medium

○ High

○ Very High

Q6 Have you ever taught makerspaces lessons before?

○ No

○ Yes

Q7 To you, what are makerspaces?

Q8 What benefits do you envisage for your students from undertaking maker activities? What do you anticipate they will learn?

________________________________________________________________\

Q9 What issues do you anticipate when teaching in makerspaces? What do you think will constrain student learning in maker activities?

Q10 What do you think will support learning in maker activities? What pedagogical strategies can you suggest for teaching in makerspaces?

Q11

| | Strongly disagree | Disagree | Somewhat disagree | Neither agree nor disagree | Somewhat agree | Agree | Strongly agree |
|---|---|---|---|---|---|---|---|
| It is important for students to acquire maker learning capabilities | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I see myself as a 'maker' | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I feel confident to | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| teach in makerspaces | | | | | | | |
| I feel enthusiastic about teaching in makerspaces | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

Q12 What support/s do you feel are the main things you need in order for your maker classes to be as successful as possible?

Q13 Please add any other thoughts or suggestions in the space below.

## 16.2 Appendix 2: Post-Professional Learning Questionnaire

Q1 Thank you for participating in the Makerspaces professional learning program. As part of the research component of this project we would like to understand your thoughts and perceptions about the professional learning that was offered. Please take the time to carefully answer the following questions. ***Note that the questions in this survey relate to the whole professional learning program that has been offered (not just to today's activities).***

Q2 Name:

Q3 Age (we won't tell!)

- ◯ 20-24
- ◯ 25-29
- ◯ 30-34
- ◯ 35-39
- ◯ 40-44
- ◯ 45-49
- ◯ 50-54
- ◯ 55-59
- ◯ 60-64
- ◯ 65+

Q4 Please respond to the following items:

| | Strongly disagree | Disagree | Somewhat disagree | Neither agree nor disagree | Somewhat agree | Agree | Strongly agree |
|---|---|---|---|---|---|---|---|
| This professional learning program was well designed | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Following this professional learning program I feel enthusiastic about teaching in makerspaces | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| Following this professional learning program I feel confident to teach in makerspaces | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

Q5 What were the main things you learnt as a result of this professional learning program?

Q6 What were the best parts of this professional learning program?

Q7 What suggestions do you have about how to improve this professional learning program?

Q8 Do you think that it is important to have professional learning for teaching in makerspaces? If so, why, if not, why not?

Q9 What concerns do you now have about teaching in makerspaces?

Q10 What support do you feel you need from here for your maker classes to be as successful as possible?

Q11 Please add any other thoughts or suggestions in the space below.

## 16.3 Appendix 3: Lesson Observation Protocol

| School name | | | |
|---|---|---|---|
| Class: | Grade level: | Teacher name: | Number students |
| Lesson Focus Area: | | | |
| Timing: | Day of week: | Time of day: | Duration of observation: |
| **NOTES: T** = teacher, **S** = student. Observe whole class during Makerspace activities | | | |
| | | | |

| **Student Learning (SL):** | **Learner Engagement (LE):** | **Task Design (TD):** |
|---|---|---|
| **Cr** = creativity<br>**Cri** = Critical thinking<br>**Kn** = Knowledge learned<br>**Sk** = Skills learned<br>**Diff** = Difficulties<br>**Alt** = Alternative conceptions<br>**Ef** = Enabling factors | **Mo** = motivation<br>**En** = engagement<br>**B** = behaviour<br>**C** = cognition<br>**E** = emotion<br>**S** = social interaction / group work / collaboration | **Desc** = brief description of task<br>**T→SS** = teacher-led component; **(SS)** = student-led component<br>**End** = closed and/or open-endedness in task design<br>**Lin** = linearity/nonlinearity in task design<br>**Ped** = pedagogy or learning theory underpinning task design<br>**Diff** = differentiation<br>**Con** = lesson containment (self-contained or within a sequence) |

## 16.4 Appendix 4: Teacher Journaling Guidelines

Thank you for agreeing to participate in the Makerspaces project – your authentic observations and insights will help teachers across the world to more effectively teach in makerspaces! To help understand pertinent issues relating to learning and teaching in makerspaces, we ask that each teacher spends approximately 20-25 minutes throughout each week documenting their thoughts and observations. Please find some guidelines for documenting your thinking below. You may also choose to include photos of student work or activities, being sure to not include identifiable photographs of students whose parents have not given consent.

(1) When did the lesson occur?
(day, date, start time, finish time)
(2) Where did the lesson occur?
(regular classroom, outdoor, 3D printing room, a mixture of places)
(3) What was the overall design of the lesson?
(e.g. 10-minute teacher instructions about ABC followed by 20 minutes of students working in pairs on XYZ and the teacher circulating amongst the groups… [Elaborate])
(4) How did you feel the lesson went?
(overall feelings, concerns, degree of confidence when conducting the lesson, etc)
(5) How did the students respond (e.g. emotionally and behaviourally) to the different sections of the lesson and how do you know?
(e.g. Students were generally attentive during the teacher instructions but lost concentration during the DEF part. Most teams enjoyed working together on the paired group work, but two of the low performing teams expressed verbal frustration at being unable to make progress because of GHI…)
(6) What knowledge and skills did you feel that the students learnt during the lesson?
(e.g. students learnt how to use the JKL tools of the software, and how to make new shapes by compositing two solids. They also learnt how to prototype as part of the design thinking cycle…)
(7) What were the main difficulties that students experienced and why (and how did they deal or not deal with them)?
(e.g. Students struggled to create the shapes that they had in their mind because they couldn't work out how to compose them using the basic solids available in the software. This meant that some students just gave up, but others sought help from peers…)
(8) Did you notice any specific misconceptions that students held and were these able to be resolved?
(e.g. Several students appeared to think that a hemisphere would fit on top of a cube to make an ice-cream shape, so I stopped the class and asked them to watch me demonstrate putting a hemisphere on a cone…)
(9) Did you try any particular teaching approaches / strategies during your lesson, and if so, how well did they work?
(e.g. During the group work I asked pairs of students to help each other if they ran into problems, which generally worked well except for the shape composition activity which everyone found difficult. When students did ask me questions, I always referred them to the online help guide so that they could develop their independent learning capabilities…)
(10) Overall, what best supported learning in this lesson and why?
(your open insights…)

(11)Overall, what would help improve learning next time and why?
(your candid thoughts…)
(12)Other
(Any other thoughts, where do you see the learning going from here…?)

## 16.5 Appendix 5: Student Focus Group Questions

1. Can you tell us about what you made? What problem did it solve? Why did you make it the way you did?
2. What did you learn from creating your product?
3. What did you enjoy most about making your product? Was there something you didn't enjoy?
4. What was most difficult about making your product?
5. Did you like using the *Makers Empire 3D* app? Why or why not?
6. What made the *Makers Empire 3D* app easy or difficult to use? Can you suggest any changes?
7. Do you think you like school more or less after the maker activities? Is school more interesting/enjoyable with maker activities? why?
8. Would you like to do more activities like this in your future classes?
9. Would you say that you are a good 'maker'?
10. Would you like to be a maker (engineer) when you grow up?

## 16.6 Appendix 6: Post-Implementation Questionnaire

Q1 (Text) Thank you for participating in the Makerspaces project. You have been truly amazing and inspiring. As part of the research component of this initiative we would like to ask you to complete one last survey in order to check how your thinking has changed throughout the whole project. Please take the time to carefully answer the following questions.

Q2 Name:

Q3 Age

- ○ 20-24
- ○ 25-29
- ○ 30-34
- ○ 35-39
- ○ 40-44
- ○ 45-49
- ○ 50-54
- ○ 55-59
- ○ 60-64
- ○ 65+

Q4 Years of teaching experience (whole years):

Q5 How would you rate your confidence in teaching with technology?

- ○ Very Low
- ○ Low
- ○ Medium

- ◯ High
- ◯ Very High

Q6 Have you ever taught makerspaces lessons before? (Easy question:-)

- ◯ No
- ◯ Yes

Q7 To you, what are makerspaces?

Q8 What benefits do you feel students have acquired from undertaking maker activities? What do you feel they have learnt?

Q9 What issues did you encounter when teaching in makerspaces? What constrained student learning in maker activities?

Q10 What do you think supports learning in maker activities? What pedagogical strategies can you suggest for teaching in makerspaces?

Q11 Click to write the question text

| | Strongly disagree | Disagree | Somewhat disagree | Neither agree nor disagree | Somewhat agree | Agree | Strongly agree |
|---|---|---|---|---|---|---|---|
| It is important for students to acquire maker learning capabilities | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I see myself as a 'maker' | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I feel confident to teach in makerspaces | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| I feel enthusiastic about teaching in makerspaces | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

Q12 What support/s do you feel are the main things you need in order for your maker classes to be as successful as possible?

Q13 Please add any other thoughts or suggestions in the space below.

## 16.7 Appendix 7: Teacher Focus Group Questions

The semi-structured focus group interviews will aim to draw out the main issues at stake in greater detail and with greater teacher reflection using the following questions:

1. Please explain to what you and your students did in your makerspace module
2. What were the best parts of the module and why?
3. What didn't work so well during the module? How come?
4. Describe how the makerspace you used supported (or not) your delivery of the module…
5. What changes would you recommend to the makerspace/s you were using? How come?
6. Do you have any evidence that suggests this affected or impacted upon the quality of students' learning?
7. How would you describe student motivation and engagement during the activities compared to your usual classes? To what did you attribute this difference? What indicators support this judgement?
8. Did you notice any difference in students' self-confidence and self-esteem as a result of the module? What indicators support this judgement?
9. What did students learn when undertaking maker activities and how do you know?
10. What were the main things you learnt as a result of running the maker module? This can relate to teaching in makerspaces, teaching with technology, or teaching more generally.
11. Did you notice any changes in your attitudes or approaches towards teaching? If so, what were they?
12. What aspects of the professional learning support were most useful to you in preparing you to run the maker module with your classes?
13. What recommendations can you make for professional learning in order to best support you to run maker modules in your classes?

## 16.8 Appendix 8: Select Photographs from Lesson Observations

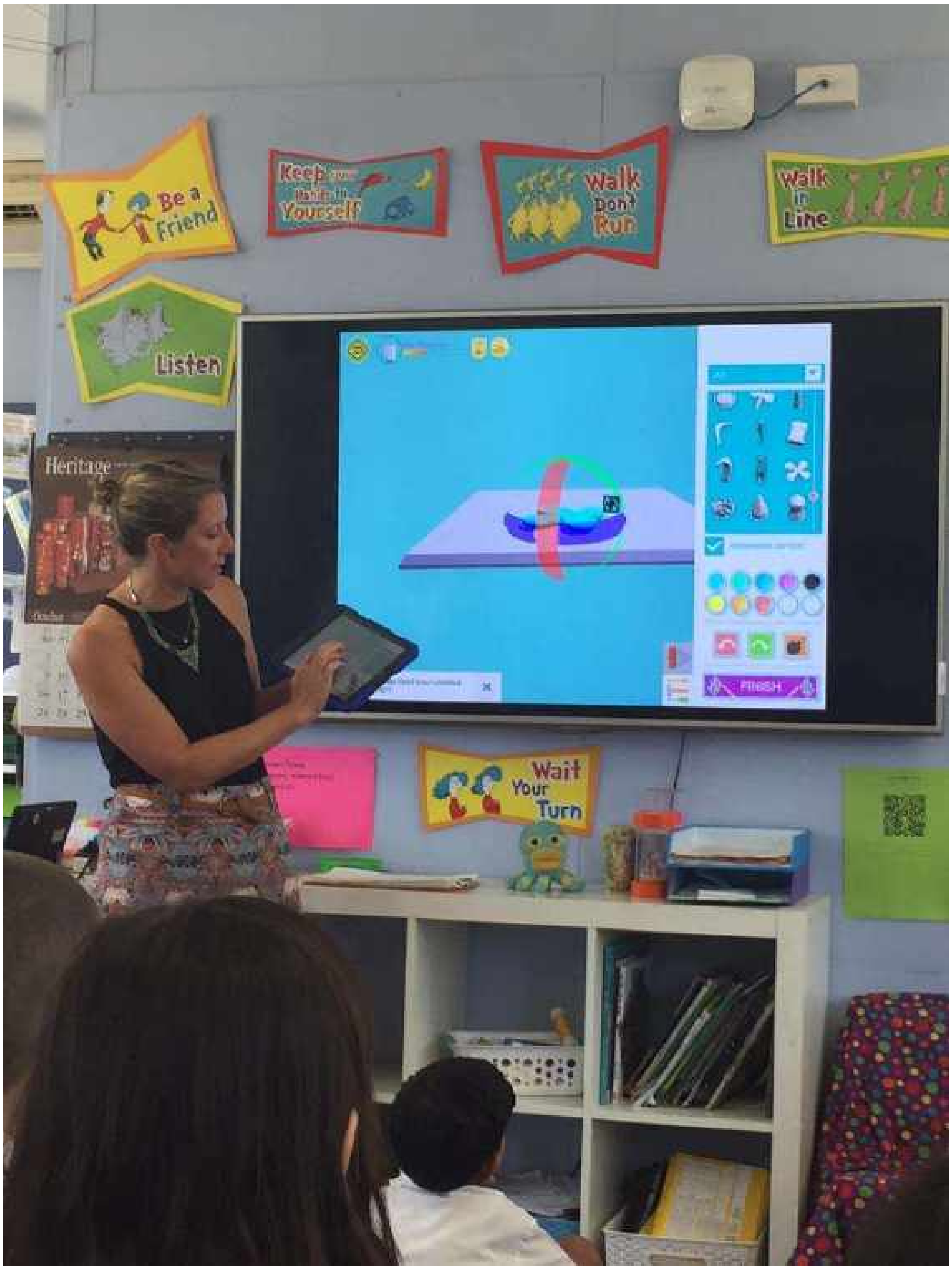


Figure 16.1 – Year 2 teacher demonstrating object rotation

Figure 16.2 – Classroom demonstration using Toy Designer

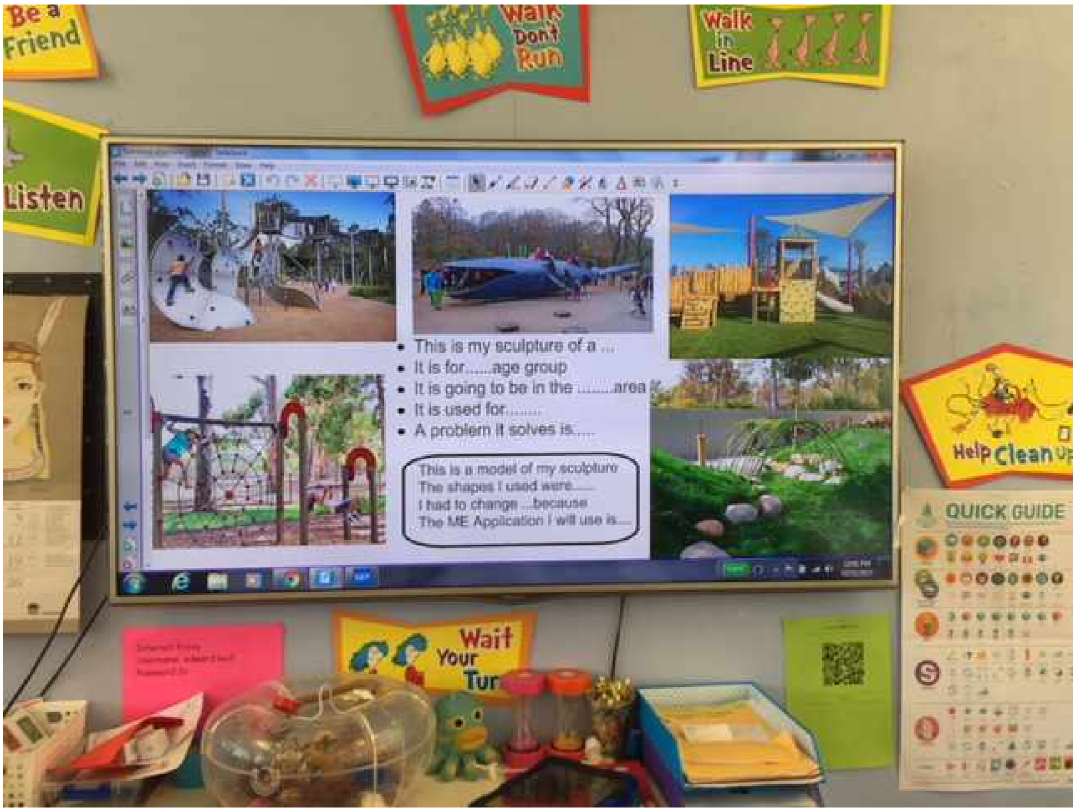


Figure 16.3 – IWB with scaffolding and example sculptures

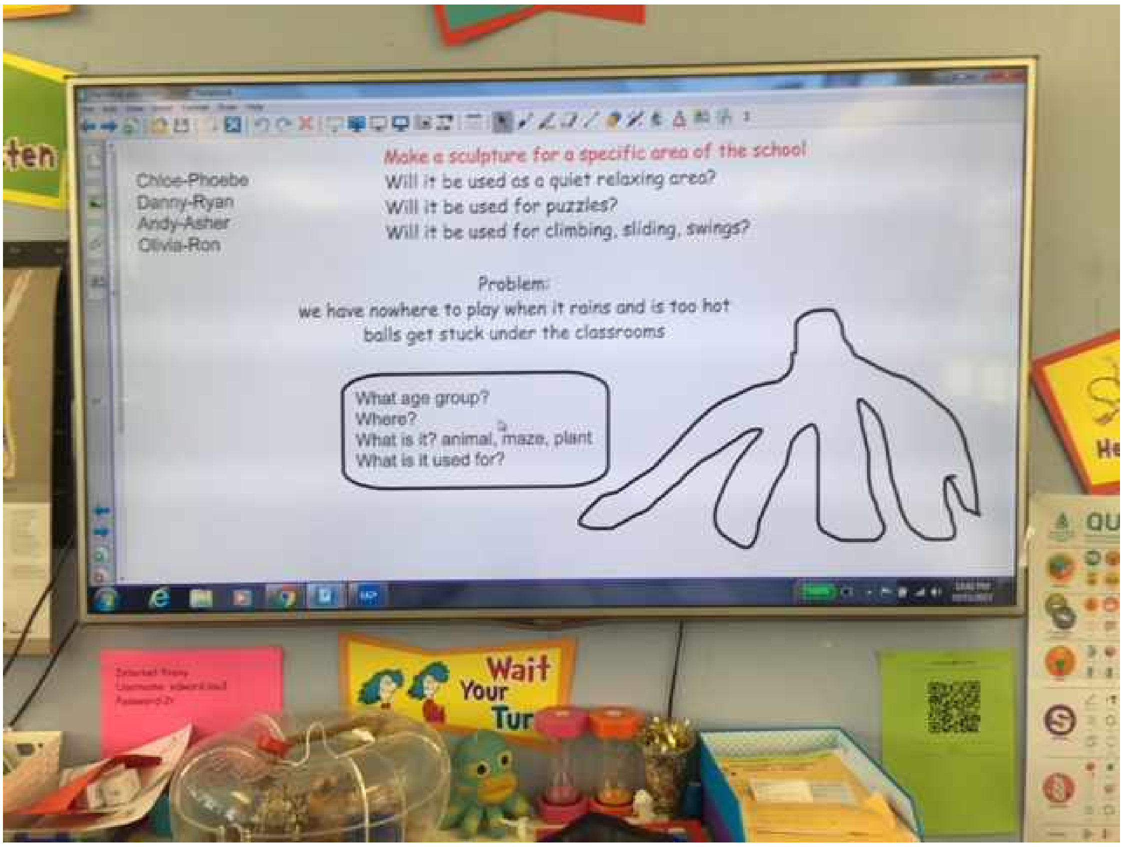


Figure 16.4 – Reflection questions for sculpture prototypes

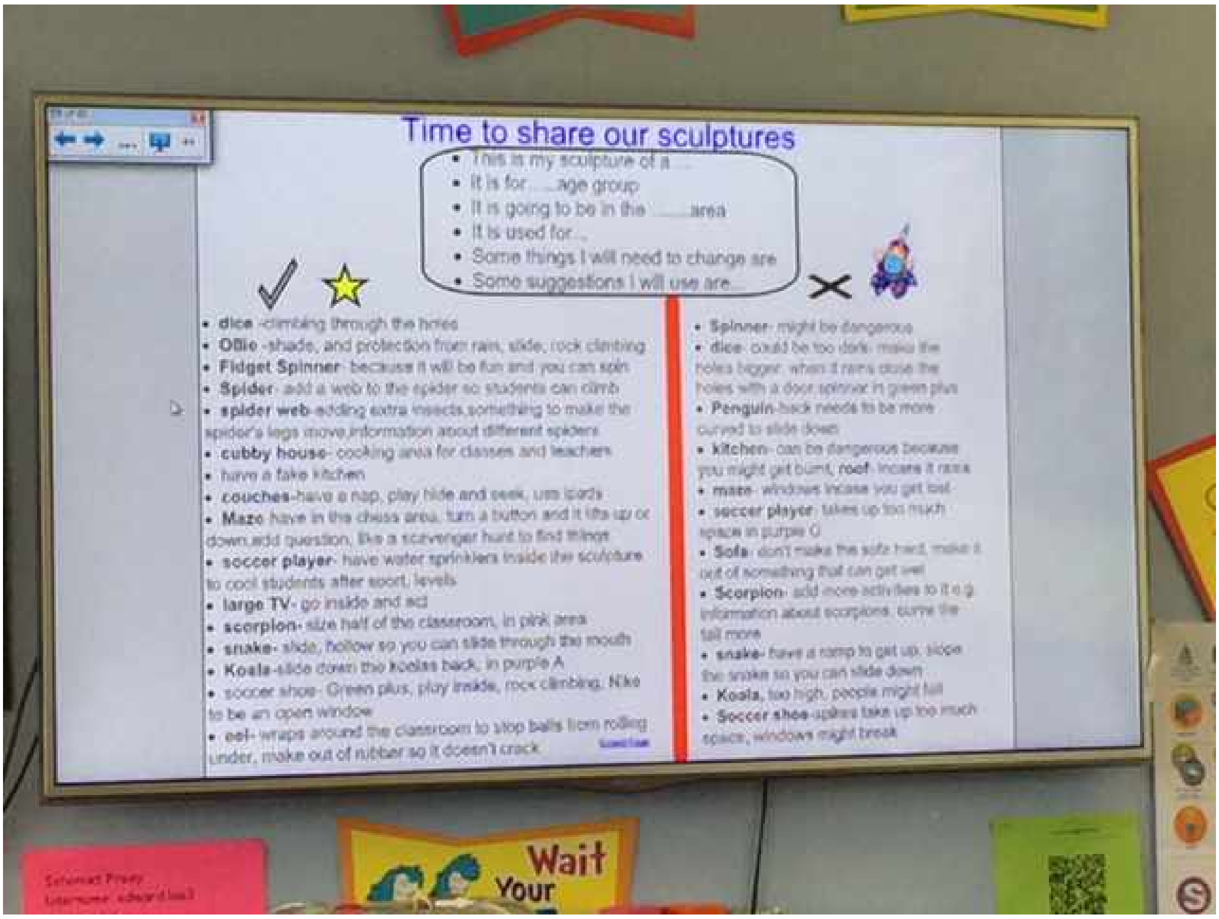


Figure 16.5 – Group evaluation questions

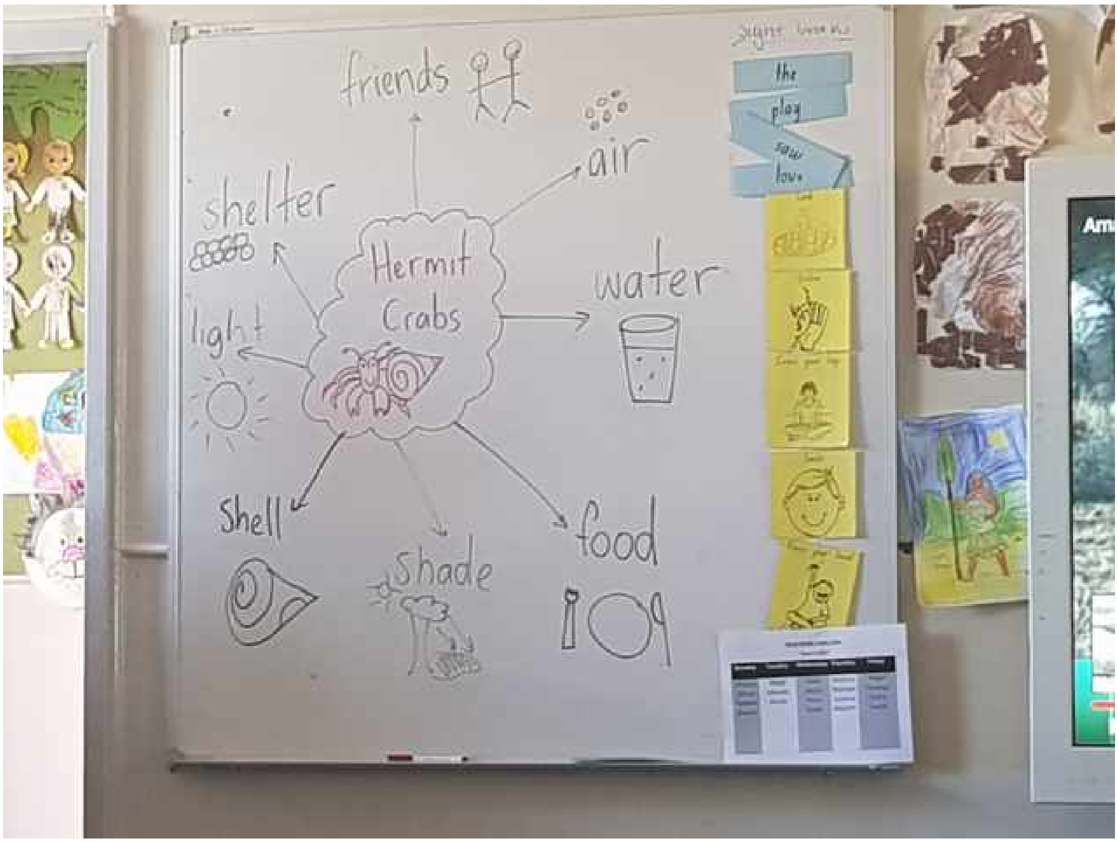


Figure 16.6 – Class brainstorm on the needs of hermit crabs


Figure 16.7 – Using a paper sketch to design an object with the Makers Empire 3D app

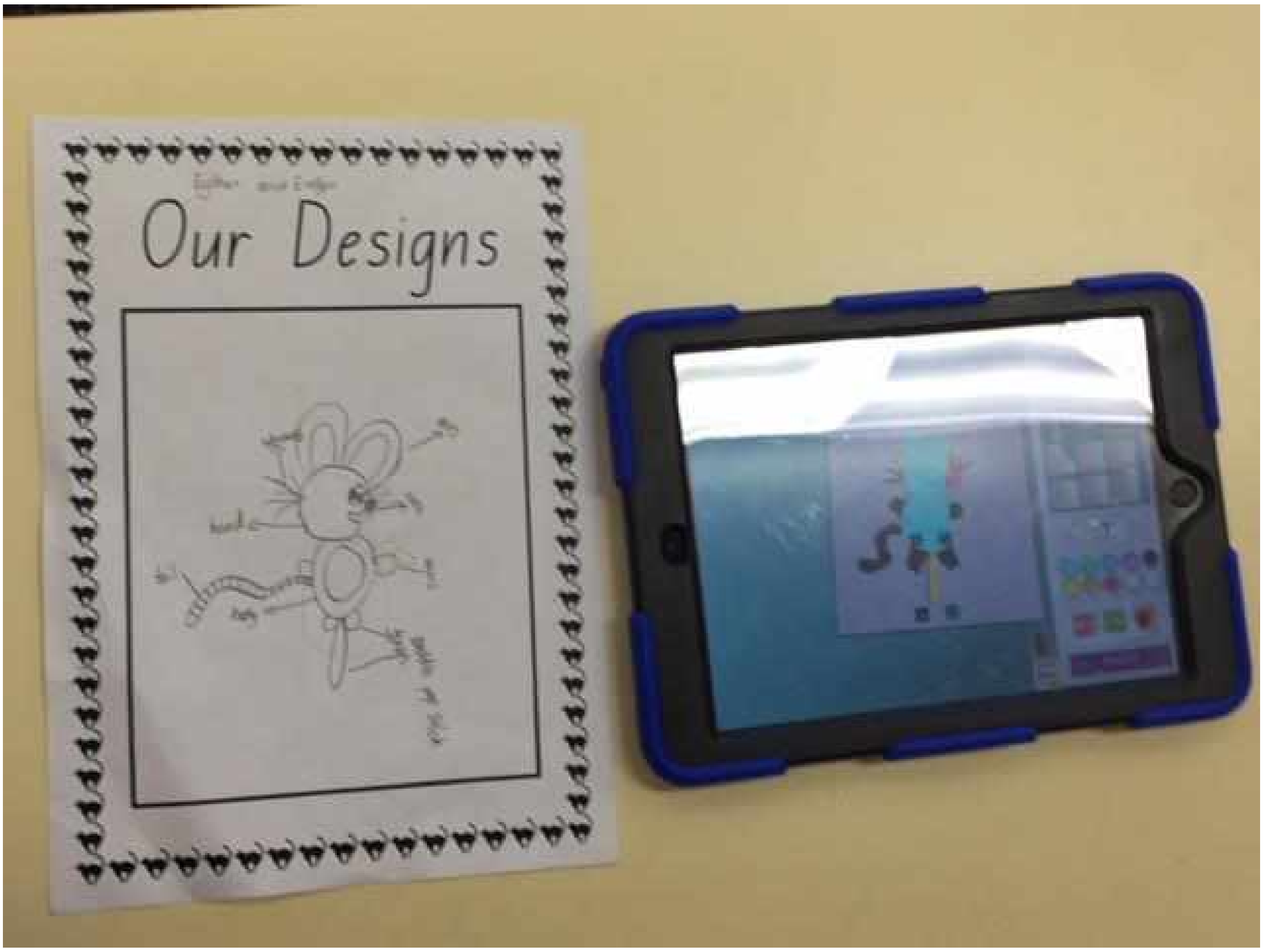


Figure 16.8 – Complete offline sketch and online model

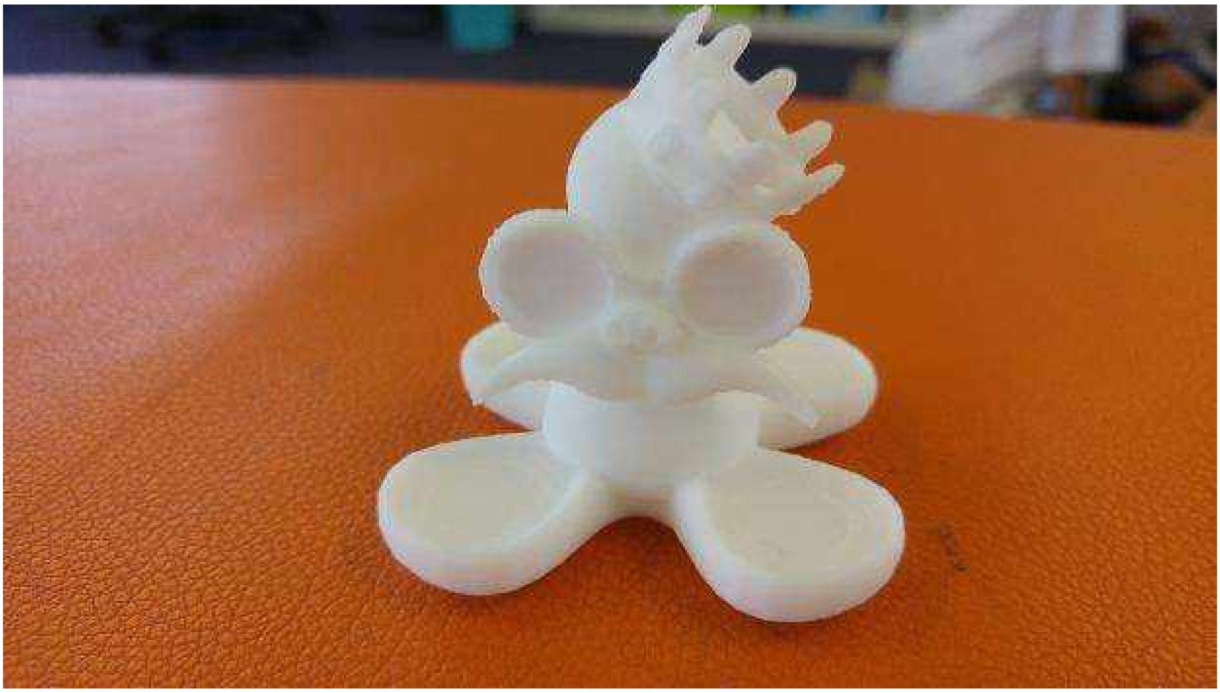

Figure 16.9 – Model spinning toy

Figure 16.10 – Class demonstration of ideations

Figure 16.11 – Typical group work

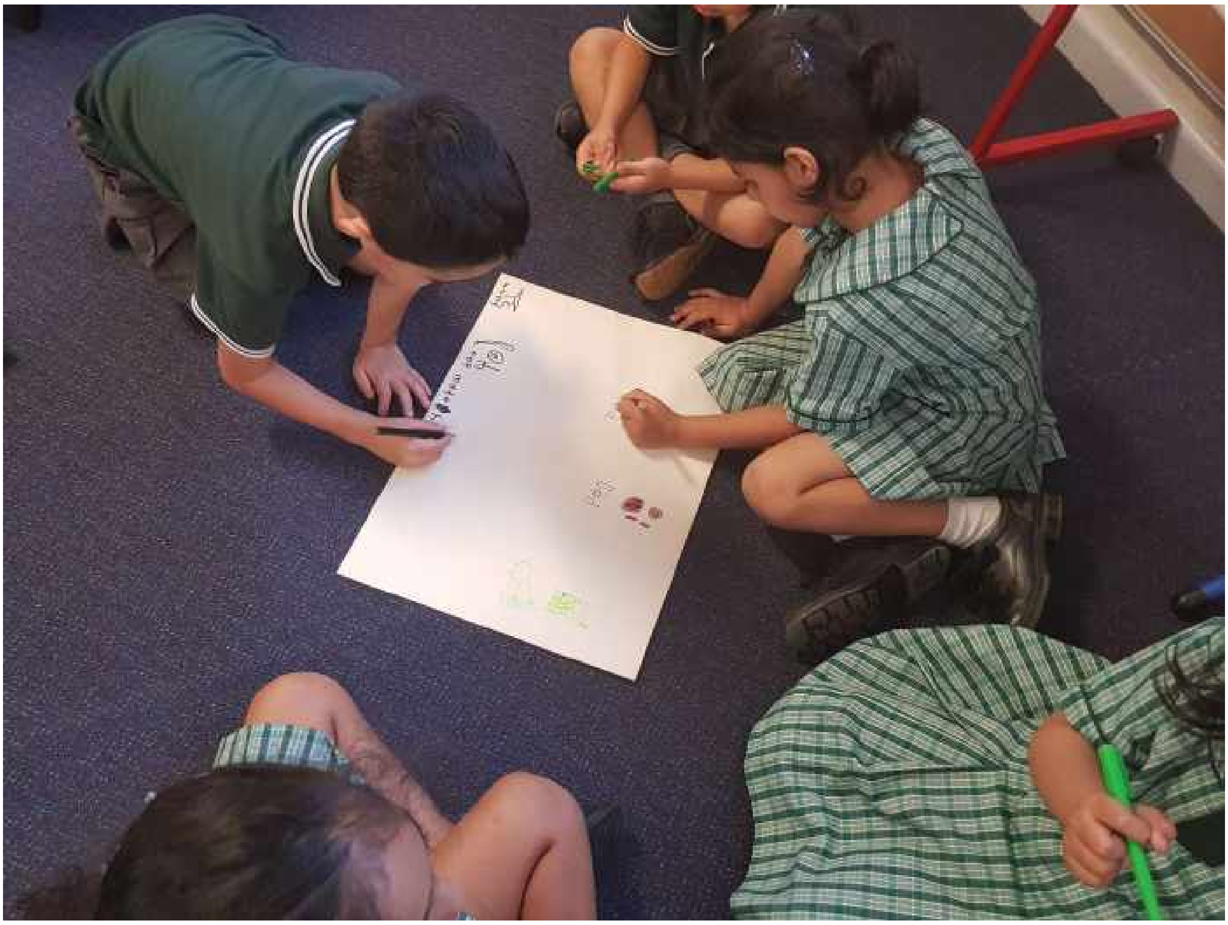

Figure 16.12 – Initial brainstorming session

Figure 16.13 – Teacher checking in with students


Figure 16.14 – Typical QR code for logging in


Figure 16.15 – Typical 3D printer setup

Figure 16.16 – Multiple 3D printers setup


Figure 16.17 – Initial herb marker sketch

Figure 16.18 – Prototype herb markers

Figure 16.19 – Teacher giving instructions in the outdoor makerspace

Figure 16.20 - Exploring objects that float or sink in the outdoor makerspace

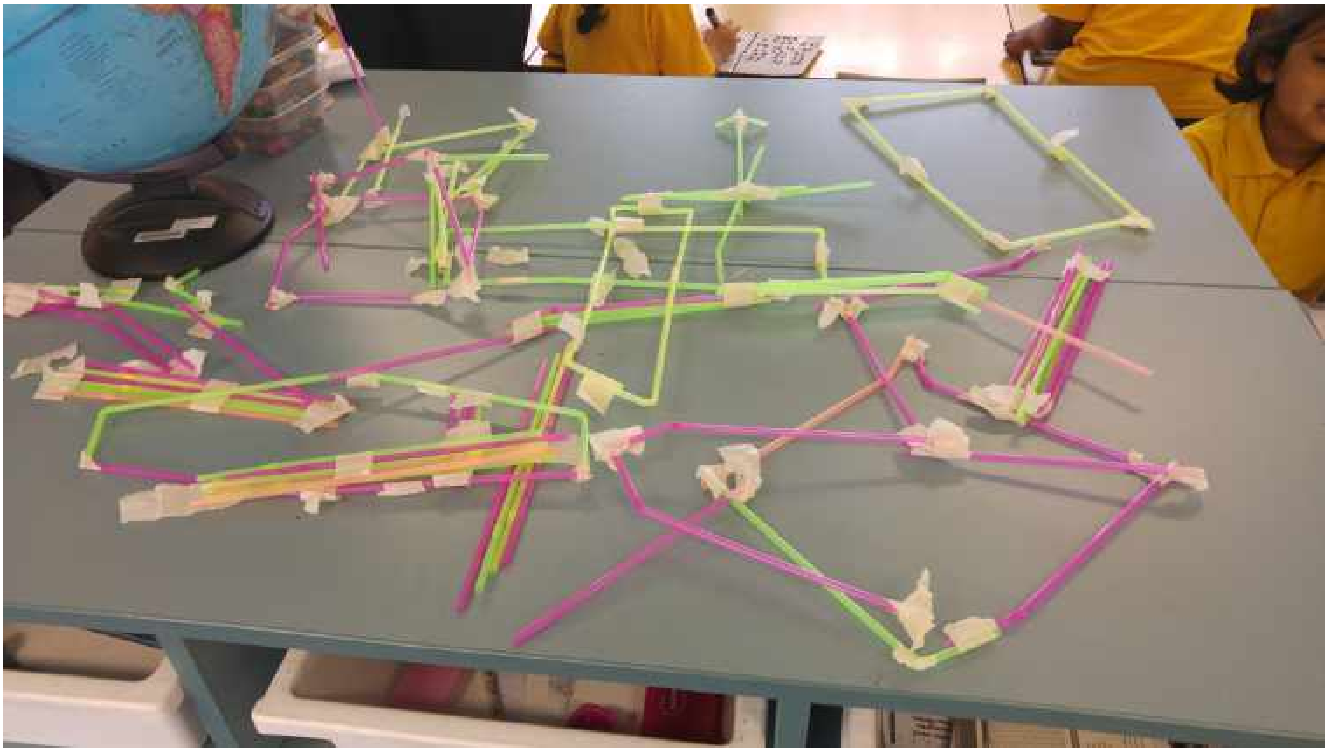

Figure 16.21 – Using offline materials to build 3D objects

Figure 16.22 – Experimenting with offline maker materials


Figure 16.23 – Students demonstrating sketched design and final design

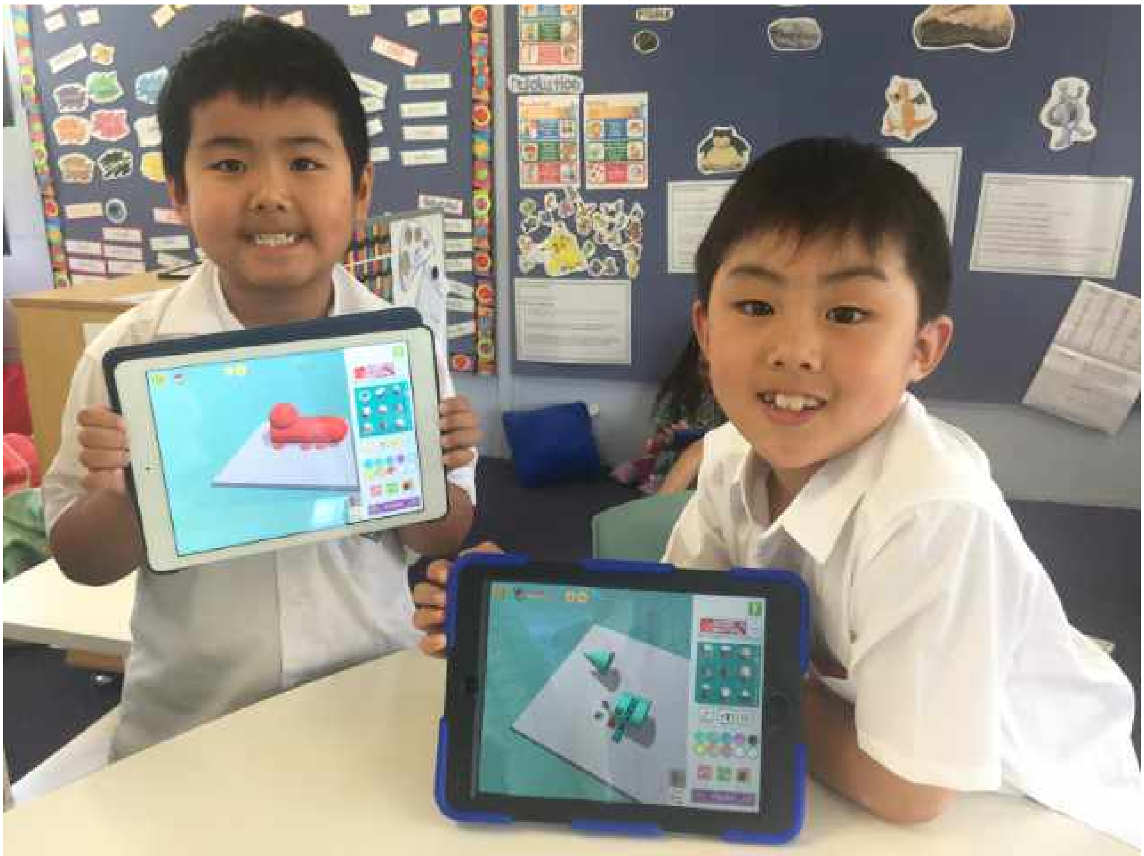

Figure 16.24 – Students displaying final designs


Figure 16.25 – Student demonstrating 3D designs and 3D-printed objects

Figure 16.26 – Student demonstrating 3D designs and 3D-printed objects

Figure 16.27 – 3D-printed objects in the hermit crab tank

Figure 16.28 – 3D-printed herb markers

Figure 16.29 – 3D-printed herb markers (coloured)

Figure 16.30 – 3D-printed herb markers (placed)