



Makerspaces in Primary School Settings

Advancing 21st Century and STEM Capabilities using 3D Design and 3D Printing

Abstract and Executive Summary Version

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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 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 21st 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)

<i>Domain</i>	<i>Descriptors</i>	<i>Code</i>	<i>Frequency (n)</i>	<i>Frequency (%)</i>
<i>Student Learning (SL)</i>	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%
<i>Learner Engagement (LE)</i>	Observed learning behaviours	Engagement	31	100%
		Collaboration	14	45.2%
		Autonomy	13	41.9%
<i>Task Design (TD)</i>	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%
<i>Teaching Approaches (TA)</i>	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 34 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.

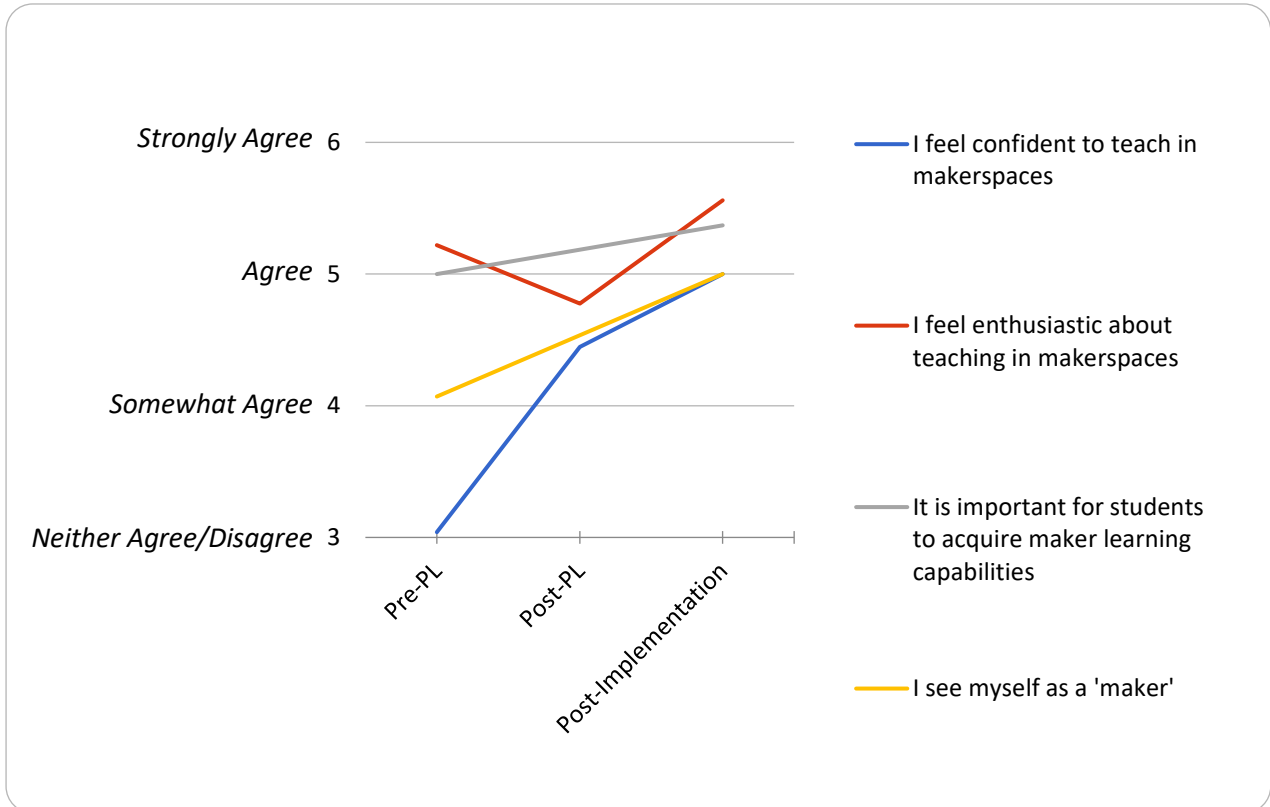


Figure 4 – Likert scale items across all stages of the study

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, $t(26)=4.22, p=0.000$, 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. 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 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.

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This document contains the abstract and executive summary of the
Makerspaces in Primary School Settings project.
For a comprehensive description of the project context, methods, analysis, and
results, please refer to the main report that can be downloaded at:
<https://primarymakers.com>