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By design: professional learning ecologies to develop primary-school teachers' makerspaces pedagogical capabilities

Abstract

Makerspaces embody a growing movement of educators promoting constructionist learning with physical materials and digital technologies such as 3D design and 3D printing. As it gains traction in K-12 settings, the maker movement represents an interesting context in which to explore how professional ecologies can equip teachers with the knowledge, skills and dispositions needed to implement twenty-first century learning in their school context. This study investigated the roles of different participants from industry, school leadership, and colleagues in influencing teachers' confidence, enthusiasm, capabilities, and beliefs when teaching in makerspaces. Utilising triangulated observations of activities through online questionnaires at beginning, middle, and end points, as well as post-project interviews, the study explored the participation of twenty-seven primary school teachers in a blended professional learning program, followed by classroom delivery of modules focussing on tablet-based 3D design applications and the use of newly-installed 3D printers. Reporting no prior knowledge or experience with makerspaces, quantitative analyses revealed significant increases in teachers' confidence and enthusiasm. Qualitative analyses of questionnaire and interview data underscored the influence of hands-on and theoretically-grounded professional learning providing practical exposure to constructionist ideas, design thinking methodologies, and 3D design technologies. Findings reveal the importance of targeted professional learning coupled with a substantial collegially-supported implementation phase, as well as support from school leaders and industry partners to promote meaningful pedagogical change in technology-mediated maker-based learning.

Keywords

Makerspaces, professional learning, professional development, primary education, pedagogies, confidence, enthusiasm

Practitioner Notes

What is already known about this topic:

- School makerspaces are a popular medium to advance students' authentic problem-solving capabilities
- Teachers often struggle to effectively infuse technology into the classroom due to issues with access, time, beliefs, professional development and institutional vision
- Research is lacking about how to effectively prepare primary school teachers to teach in makerspaces

What this paper adds:

- Professional development involving constructionist pedagogical frameworks and active learning experiences significantly improved novice teacher confidence to teach in makerspaces
- Teachers expressed several concerns prior to implementing their makerspaces modules, including technological problems, inadequate resourcing and inappropriate spaces
- Teachers' enthusiasm for makerspaces only increased following module implementation with the support of their professional learning community

Implications for practice and/or policy:

- Structured professional development, supplementary online professional development and an extended application phase are key supports for teacher professional learning in makerspaces
- Professional learning should be hands-on, theoretically grounded and socially-oriented
- School makerspaces pedagogy requires appropriate resources, infrastructure, spaces, professional development and time, as well as a culture that values productive failure

Introduction

In schools, universities, libraries and community centres around the world, makerspaces are increasingly recognised for promoting creativity, critical thinking, and problem solving through hands-on design with physical materials and digital interfaces. Though previously the domain of out-of-school activities, makerspaces are now becoming more mainstream in both K-12 and higher education settings (Becker et al., 2018; Freeman, Becker, & Cummins, 2017). Their growing presence there highlights the need for evidence-informed professional learning to equip teachers with the knowledge and skills needed for effective practice. While the research literature on the educational benefits of makerspaces is steadily growing, findings relating to the influence of professional learning on teacher practice remain elusive.

Empirical research and literature reviews relating to digital technology integration reveal several reasons why teachers struggle to effectively integrate technology into the classroom, including problems with access, time, beliefs, professional development and institutional vision (Kopcha, 2012). Inadequate training and development mean that teachers cannot develop required competencies to transform their technology-enhanced learning practices (Blin & Munro, 2008). Research suggests that well-developed professional learning communities can have a positive impact on teacher practice (Vescio, Ross, & Adams, 2008). However, the activities that occur as part of the community of practice play a highly influential role in promoting change in teacher attitudes and practices with technology (Kopcha, 2012). Effective teacher professional development requires change at several levels of educational systems – political, institutional and individual (Twining, Raffaghelli, Albion, & Knezek, 2013).

Increasing opportunities afforded by technology mean that there is a current and pressing need for research on situated professional development in K-12 settings (Kopcha, 2012). At the same time, there is an evidence-driven and growing shift "from delivering and evaluating professional development programs to understanding and supporting authentic professional learning" (Webster-Wright, 2009, p. 709). It has also been proposed that to truly understand factors affecting technology use in schools, a systemic or 'ecological' approach is required that facilitates interactions from cognitive, social, organizational, technological and psychological perspectives in the context of the broader environment (Zhao & Frank, 2003).

Consequently, this study examined the influence of a makerspaces professional learning program involving an initial professional development phase and a situated implementation phase on teachers from a holistic perspective, in order to identify ecological factors that support and constrain systemic change.

Makerspaces and Teacher Professional Learning

Typically informed by constructionism, learning in makerspaces often embodies learner-led inquiry, creativity and making. The leading exponent, Papert (1986), states that constructionism is predicated on the philosophies of constructivism, describing learning that "is most effective when part of an activity the learner experiences as constructing a meaningful product" (p. 2). As Bevan (2017) elaborates, "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). While Papert's work mainly focused on children's use of digital tools, his basic theoretical ideas on constructionism as "learning by making" (Papert & Harel, 1991, p. 7). To support maker pedagogies, Papert later proposed the "eight big ideas behind the constructionist learning lab" (Papert, 1999). These include learning by doing, building with technology, hard fun, learning to learn, taking time, failing well, teachers as learners, and learning together.

Instructional models such as IDEO's *Design Thinking for Educators* (Fierst, Diefenthaler, & Diefenthaler, 2011), Stanford University's *d.school* (Hasso Plattner Institute of Design, 2017), and *IDESiGN* (Burnette, 2005) have been associated with learning and teaching in makerspaces. Often with reference to industry-based design, design thinking promotes principles, cases and strategies for supporting the design process. Exploring the connections between design thinking and maker-based learning, Freeman et. al. (2017) note that design thinking encourages "the notion that failure is an essential part of learning, [which] is oft-cited but is not always seamlessly ingrained in school culture", while also 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). Of the models available, IDEO's (Fierst et al., 2011) detailed handbook includes scaffolds, stimulus, first-hand accounts, and advice. The authors of the handbook position teachers as the designers and propose that although design thinking can be used to face any challenge, there are consistent school challenges that "centre around the design and development of learning experiences (curriculum), learning environments (spaces), school programs and experiences (processes and tools), and system strategies, goals and policies (systems)" (p. 12). Accompanying resources in the handbook therefore appear suited to professional learning programs that encourage teachers to adopt the role of designers and envisage positive changes in their school context, professional practice, and impact on students' learning.

Makerspaces have also been recognised as transformative element in early childhood education by promoting authentic, real-world creativity through the design process and enabling integrated STEM learning (Ashbrook & Nellor, 2015; Honey & Kanter, 2013; Resnick, 2014). Moreover, recent research recognises the capacity of makerspaces to integrate traditional subject disciplines in less traditional ways. As Bevan (2017) relates, makerspaces challenge "traditional ideas of what counts as STEM, what counts as learning, and perhaps what even counts as science education" (p. 76). Likewise, some argue for the use of inquiry-oriented instructional models such as Project-Based Learning to support making and creativity in the early years. In particular, Marshall and Harron (2018) stress that "following paradigms of learning such as PBL, making indeed can, in fact must, serve as a basis for STEM learning" (p. 3).

Despite the challenges of accurately framing the creative design process in the early childhood classroom, research suggests that play is the dominant support for creative thinking. For example, in a study of a weekly play program focusing on cooperative interaction, Garaigordobil and Berrueco (2011) found that structured play positively impacted on verbal and graphic creativity, and also on creative behaviours. In a similar study exploring a range of play-based activities, Robson and Rowe (2012) found that "activities such as gardening and construction were as valuable for supporting creative thinking as ones traditionally associated with creativity, for example, music and painting. Outdoor play of all kinds and socio-dramatic play were particularly effective contexts" (p. 349). In a study of science activities in early childhood settings across nine countries, Cremin et. al. (2015) identified synergies between inquiry-based and creative approaches, pointing to links between creativity and problem-solving, dialogue, play, reasoning and reflection.

Recent research recognises the need for "educator preparation to understand… the novel pedagogies associated with making" (Oliver, 2016a, p. 160). Maker pedagogies typically encompass a wide range of approaches that include teacher-learner and school-industry partnerships, project- and problem-based learning, integrated curricula, authentic learning, and learner-led inquiry. Although limited, makerspaces professional learning research suggests need for professional learning that positions teachers as learners, affording them the same opportunities to experience the effect of maker pedagogies on their learning (Oliver, 2016; Paganelli et al., 2017; Purpur, Radniecki, Colegrove, & Klenke, 2016). Supporting this, Harron and Hughes (2018) advocate "giving teachers more time to explore [maker] materials with lesson development support through further professional development, curriculum specialists, or with other educators" (p. 12). Similarly, Bower et. al. (2018) found that experience-oriented professional learning with makerspaces could play a role in helping teachers shift towards pedagogies that are "more open, communal, collaborative, purposeful, contingent and dynamic" (p. 104), but did not unpack how the nature of professional learning could affect the development of different teachers.

Consistent with the growth of makerspaces professional learning, there an increasing volume of empirical research on professional learning among teachers in lower primary school settings, although the number of studies systematically examining situated professional learning experiences across multiple teachers and classes is limited. A comprehensive literature review of makerspaces research across a range of formal and informal contexts that included schools, museums, libraries, maker faires, and after-school clubs, the *MaKEY Project* (Marsh et al., 2017) concluded:

> it is clear that few research studies are identified that focus on examining the value of makerspaces in the early childhood years. This is a distinctive gap in knowledge, which needs to be addressed if understanding is to be developed of the way in which makerspaces might facilitate young children's development in digital literacies and creativity (Marsh et al., 2017, p. 100).

This finding is echoed in other reviews indicating an absence of empirical research on makerspaces in these contexts, and an almost complete absence of the role of teacher professional learning in facilitating these (Bolstad, 2015; Papavlasopoulou, Giannakos, & Jaccheri, 2017).

Study

Context and Background

The *Makerspaces in Primary School Settings* project investigated teacher implementation of makerspaces in Kindergarten to Grade 2. Makers Empire – an Australian-based education technology company behind the development of a 3D design and printing app – provided a blended professional learning program to teachers from three government primary schools in a large metropolitan area. Based on the Australian Index of Community Socio-Educational Advantage (ICSEA), all three schools were moderately above the average index of 1000. With over 1100 students, the largest of the three schools (with an ICSEA score 1144) had previously participated in a research hub partnering with the local university, while the two smaller schools (both with approximately 200 students, with an ICSEA score of 1083) were selected based on their involvement in similar technology-based studies with the hub. In addition to conventional subjects, the Kindergarten, Grade 1 and Grade 2 curriculum comprised an integrated *Science and Technology K-6 Syllabus* (NESA, 2018) within which makerspaces concepts and design thinking could be situated.

Two face-to-face training days were separated by an intervening period of five weeks, during which online support was provided in the form of an *Edmodo* group page with discussions and weekly webinars (professional development phase). Teachers were given access to the company's *Makers Empire 3D Design* app, which was installed on school-provided iPads and used with newly-purchased

3D printers. Following the professional development phase, teachers designed and delivered units of work integrating both physical materials and 3D design technologies over approximately five weeks (implementation phase). A wide range of topics were observed across the makerspaces units, 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 (for further details of the sorts of projects that were completed in each class, see the *Makerspaces in Primary School Settings* report, available at http://primarymakers.com). Teachers used a mix of online and offline activities, as well as a range of teaching strategies including explicit instruction and open-ended inquiry. Throughout the study, a research team from an Education department in the research university examined teachers' participation and perceptions.

Two research questions guided data collection relating to the professional learning:

- How is teacher capacity to embed design thinking processes through maker-based pedagogies developed through a blended and situated professional learning program?
- How can teachers best be supported to develop their maker pedagogical capabilities at a school and systemic level?

A major component in the professional learning program was the use of IDEO's *Design Thinking for Educators* model of design thinking (Fierst et al., 2011) to support teachers in their design process.

Research participants

Twenty-seven teachers were involved in the professional learning program. These teachers were predominantly female (n=26, 96.3%), with a majority in their first ten years of service (n=17, 63%). At the time of data gathering, most participants (n=15, 55.6%) were aged between 20 and 39 years (M=37.7), while a significant minority (n=11, 40.7%) were aged between 40 and 69 years. Teachers were teaching in either Kindergarten, Grade 1 or Grade 2 (with students aged 5-8), with class sizes ranging from approximately 20-24 students. All teachers reported having no prior knowledge of, or experience teaching in, makerspaces.

Data collection

A baseline online questionnaire was delivered to teachers before they commenced the training. In addition to demographic items that included age, gender, and number of years teaching, the questionnaire measured general confidence with technology with a five-point fully-anchored scale responding to the question, "How would you rate your confidence in teaching with technology?". Teachers also rated their confidence and enthusiasm for teaching in makerspaces using a seven-point fully-anchored scale in relation to the statements “I feel confident to teach in makerspaces” and “I feel enthusiastic about teaching in makerspaces”. The questions are further detailed in Appendix S1.

During the training, researchers recorded observations of teachers’ interaction in the face-to-face and online professional learning activities, following which a post-professional learning questionnaire containing identical items measured changes to their knowledge and beliefs. In addition, the post- questionnaire also invited teachers to evaluate the structured professional learning. Teachers were asked to share what they learned in the program, what they felt were its best features and its relevance for their practice, and propose suggestions for improvement. Teachers were also invited to state any concerns they held and detail further support they believed was necessary. At the end of the study, confidence and enthusiasm were again measured through an identical post-implementation questionnaire, and teachers were invited in focus group interviews to share their insights on the professional learning they received and their teaching implementations (see Appendix S1). All 27 teachers provided responses to all surveys, and 25 teachers participated in the focus group interviews.

Data analysis and reporting

Observations, surveys and interviews were triangulated in order to overcome perceived limitations of using individual data sources (Desimone, 2009). Quantitative data from the questionnaires were analysed using the *Statistical Package for the Social Sciences* (SPSS), Version 24. The research team generated descriptive statistics and T-Tests of the closed questions in each of the questionnaires and evaluated changes to confidence and enthusiasm through repeated measures ANOVA. Qualitative analysis of the open questions in the post- questionnaire was undertaken with *QSR NVivo*, Version 11. These data were explored inductively, with category systems and two orders of codes generated to show main themes (for example, “Suggested Improvements”) and sub-themes (for example, “Training Support”). Codes were then enumerated to explore the frequency with which themes occurred and identify patterns and relationships. Analysis of teachers’ participation within the online space was conducted by archiving the *Edmodo* page, expanding and sorting posts chronologically, performing frequency counts, and grouping posts into topic areas. Throughout data analysis, recurrent themes, topics and issues were explored to establish clear frames of reference. Primary sources of evidence in the form of participant quotes are used throughout the reporting to support validity.

Findings

First, to contextualise findings, teacher perceptions following the professional development activities are explored by presenting a theme-based summary of the inductive analysis of teachers' responses to the open questions in the post-professional development questionnaire. Synthesising teachers' responses to the closed questions across all three questionnaires, the paper then explores the development of teacher confidence and enthusiasm for teaching in makerspaces. Finally, findings from the post-implementation open-ended survey responses and focus group interviews are detailed to provide an holistic understanding of teacher experience and change.

Professional Development Program Activities

Through triangulated observations, the research team examined all activities in the professional development program. Table 1 in Appendix S2 outlines four activities that were selected to clearly demonstrate how the initial training program supported the development of teachers' capacities to embed design thinking processes through maker pedagogies. For instance, key concepts – including several of Papert's (1999) "Eight big ideas" – are mapped to participants' thinking to show how constructionism underpinned the design and delivery of the training.

Despite all teachers participating in both face-to-face training days, less than half (n=11, 40.7%) opted to participate in the Edmodo page, as measured by at least one recorded post within the page. T-test comparisons of the participating and non-participating groups were performed in relation to the demographic variables of *years teaching, gender*, and *school*. Only one variable – years teaching – showed a marked difference between groups, with *Edmodo* participants on average being significantly more experienced (M=18.45, SD=10.83) than non-*Edmodo* participants (M=6.1, SD=6.95), $t(25)=3.72$, $p=0.001$. This suggests that more experienced teachers deemed the online professional development support to be more valuable.

Post-Professional Development Perceptions of Teachers

Theme 1: Key Outcomes from the Initial Professional Development Phase

Almost all teachers (n=25, 92.6%) commented on positive program outcomes. A substantial portion (n=11, 40.7%) felt that the professional learning enabled them to recognise affordances of makerspaces, such as one Kindergarten teacher who elaborated, "many teachers and students are unfamiliar with the concept of makerspaces… [so professional learning] provides more confidence and guidelines for teachers to introduce it". Seven teachers (25.9%) commented on how the professional learning had helped them to improve their understanding of maker pedagogies, with one Grade 1 teacher commenting that she was more able to support open-ended inquiry and give "students a problem to solve, so that they are more engaged in the task". Several teachers (n=5, 18.5%) were pleased that the program afforded them the opportunity to collaboratively develop maker units of work. As one Grade 1 teacher explained, "there was a lot more planning time… which allowed us to really develop our ideas… and gave us more of a direction about what will be created and how it can be achieved". Eleven teachers (40.7%) identified gains in their capabilities to teach problem-solving skills, including one Kindergarten who felt she was now "looking at problem solving in a new way" and another, who felt she could now teach students how to solve "real life problems rather than teaching the concept as it is". Design thinking skills were also key – for instance, with a Kindergarten teacher commenting that she now understood "the design thinking process that occurs when creating a 3D item". Finally, a sizeable portion (n=16, 59.3%) referenced gains in confidence with technology, such as one Kindergarten teacher who could now "use 3D technology to further enhance children's thinking".

Theme 2: Best Aspects and Suggested Improvements for the Initial Professional Development Phase

Over two thirds of the teachers (n=21, 77.8%) expressed opinions about effective makerspaces professional learning, with nine (33.3%) specifically referring to "hands on" and "experiential" learning. Many seemed to appreciate the opportunity to learn through experience with the technology, which a Grade 1 teacher indicated helped "to gain confidence when using the app and troubleshoot problems". One Kindergarten teacher 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". Another Kindergarten teacher valued networking with colleagues, "so that we can hear about what others have done and ask questions along the way". One Grade 2 teacher identified value in between-school teacher professional networks, where she could meet "new people and sharing ideas, including assistance with problem solving". Elsewhere, references were made to needing more "expert guidance", "explicit instructions", "time to collaborate" and "peer sharing with colleagues".

The *Edmodo* page was critiqued by some participants (n=4, 14.8%), who felt their interaction on the page was less helpful than the face-to-face sessions. Six teachers (22.2%) desired more supporting resources – as one Kindergarten teacher put it, "more detailed instructions on how to use the app". One Grade 1 teacher elaborated that "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 more one-on-one support could have been provided during the face-to-face sessions, with one Kindergarten teacher commenting 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”.

Theme 3: Concerns Moving Forward Following the Professional Development Phase

The final theme included teachers’ concerns moving forward. Four teachers (14.8%) identified the role of support from Makers Empire, such as a Grade 1 teacher who valued “having an expert who uses the program to lead us through the app and the design process”. Five teachers (18.5%) described school-based IT support as both a current inadequacy and a future need. One Kindergarten teacher wanted “an extra pair of hands to help out with technology”, while another needed “someone to be in the classroom when using the app with students… [because] kindy children will need a lot of one-on-one assistance”. Eight teachers (29.6%) expressed the importance of collaboration with their classroom and school leader colleagues, such as a Grade 1 teacher who believed she needed support from “fellow teachers, to bounce ideas around and see how everyone is going in the process”.

Eleven teachers (40.7%) expressed concerns about supporting learners when teaching in makerspaces. One Grade 2 teacher believed “children’s ideas will be too hard to form designs”, while a Grade 1 teacher was concerned “that it will take too long on their design project on the app, and they will never finish in time”. Another Grade 1 teacher said that the main challenge was “keeping it simple and effective for young students”. One Grade 1 teacher questioned “how quickly the students will pick up using the app”. One Kindergarten felt her students “may take longer to master the skills to use the app before the actual designing process”.

Six teachers (22.2%) referenced problems with technology as a concern they had moving forward, including broader technology issues within the school and those they perceived were likely to be encountered while teaching their units. Three teachers all feared “technology not working”, noting exacerbation when IT support was limited. For instance, one Kindergarten teacher elaborated that “there have been many issues already with the 3D printers, iPads and computers” and added she was “concerned about what will happen when I don't have the support we have had during PL sessions”. A Grade 1 teacher conceded at this stage of the project that most “technical issues can’t be known until everyone starts using the software”.

Twelve teachers (44.4%) expressed resources and infrastructure concerns. Three teachers (11.1%) had concerns about the infrastructure in their schools. A Grade 2 teacher was unhappy with “the allocation of resources" across classes, while a Kindergarten teacher was concerned about the "lack of space and storage for resources". One Grade 2 teacher thought that "a cheat sheet with video tutorials would be useful when using the tools".

Finally, twelve teachers (44.4%) expressed concerns about having enough time for professional learning, planning, and teaching in makerspaces. One Kindergarten teacher conceded that she hadn't "had enough time to play around with the app… and I don't understand enough yet". Seven teachers (25.9%) were particularly concerned about curriculum constraints. One Grade 2 teacher commented on the impact of limited time on the quality of learning in makerspaces, believing 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". Similarly, one Grade 1 teacher 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". Finally, teachers 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".

Confidence and enthusiasm across the program

In response to the question "How would you rate your confidence in teaching with technology?" on a five-point (0-4) scale, most teachers indicated a "medium" level of confidence (M=1.81 out of 4, SD=0.79). Using this measure, three general confidence clusters were created by grouping scores of 1 0 and 1 ("Very Low" and "Low"), and scores of 3 and 4 ("High and "Very High"), while keeping the "Medium" score of 2 separate. This variable was then used to explore mean differences for the seven-point Likert scale items "I feel confident to teach in makerspaces" and "I feel enthusiastic about teaching in makerspaces. The graphical representation of mean responses for the groups at three time points – pre-professional development, post-professional development and post-implementation – revealed how teachers' perceived confidence and enthusiasm for makerspaces evolved throughout the study (see Figure 1 and Figure 2). Of note, participants in the *low/very low* technology confidence group generally reported, on average, lower confidence and enthusiasm than those in the *medium* or *high/very high* groups. Notably, enthusiasm among the *medium* and *low/very low* groups waned in the post-professional learning measure, before rebounding in the post-implementation measure.

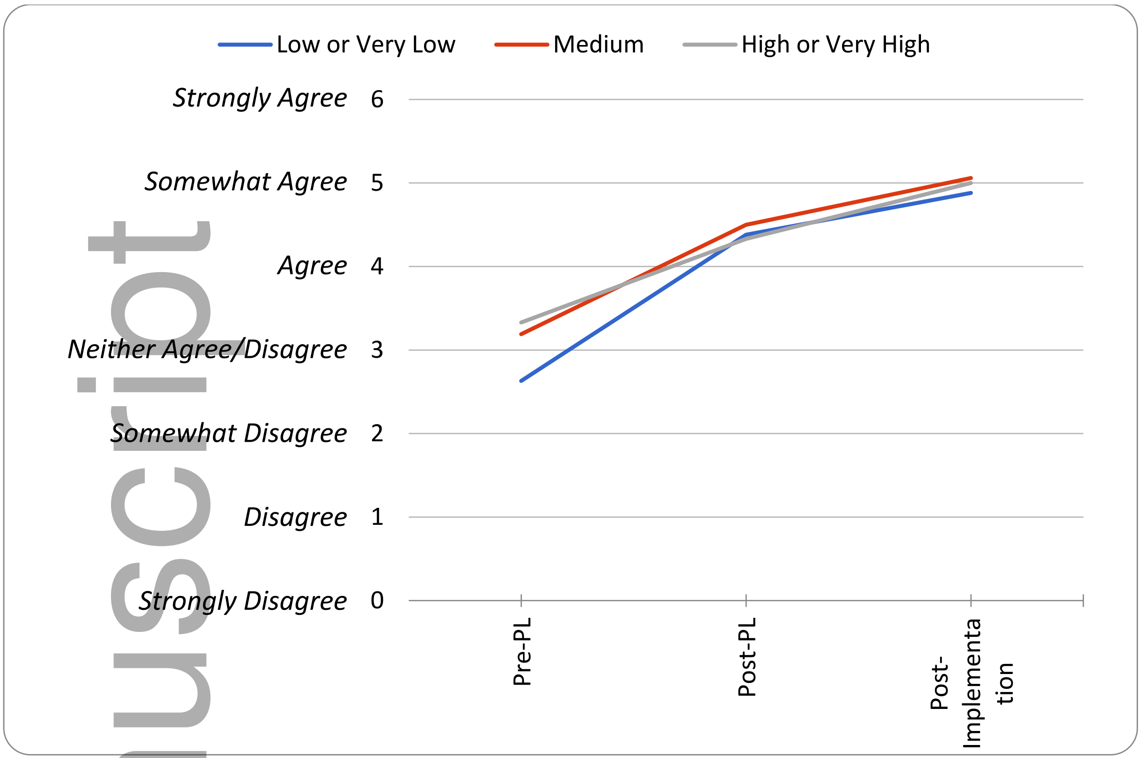

Figure 1 - Mean Confidence Teaching in Makerspaces by Technology Clusters

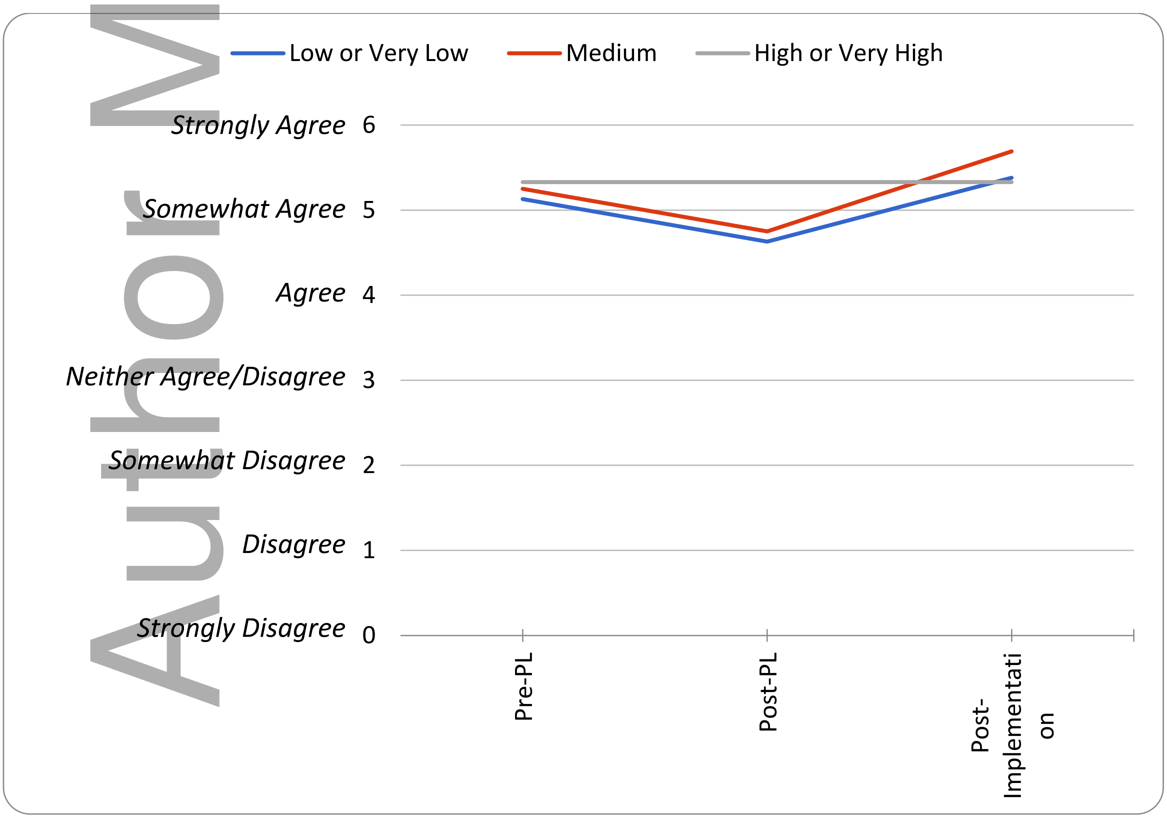

Figure 2 - Mean Enthusiasm Teaching in Makerspaces by Technology Clusters

To explore whether differences of mean for confidence and enthusiasm were statistically significant for the combined group of teachers across all three stages of the project, a repeated measures ANOVA was performed for each construct. Levels of confidence were significantly affected by the stage of the study, $V = 0.73$, $F(2, 25) = 33.33$, $p < .001$, and levels of enthusiasm were also affected by the stage of study, $V = 0.36$, $F(2, 25) = 6.94$, $p < .004$. Post-hoc comparisons using T tests with Bonferroni correction revealed 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 also significantly different to the post-professional learning score. Similarly, 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.

Post-Implementation Perceptions of Teachers

In the post-implementation survey, many teachers (n=17, 63%) commented on technological problems such as internet connectivity, access to Wi-Fi, malfunctioning iPads, app issues, and 3D printing problems. However, teachers expressed less concern about their confidence to teach in makerspaces, with many reporting the positive benefits. Five (32%) identified how improvements to their confidence impacted on student learning. As one Year 2 teacher explained, "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'". More commented on resourcing issues in the post-implementation survey (n=17, 63%) than in the post professional-development survey (n=8, 30%), including access to iPads, physical materials for offline making, and a "dedicated Makerspace area … instead of wasting time packing up". However, the crucial role of collegial support was identified as important by twelve teachers in both the post-professional development and post-implementation surveys - both "technical support to rectify any hardware or software problems that arise" and "support from other teachers, for example, through team teaching. Time was still a concern, but only for a minority of teachers (5, 14.8%).

In the post-implementation focus groups, teachers still identified that problems with 3D-printers at times constrained their lessons, but many were able to see benefits in terms of improving students' motivation and design thinking capabilities through reification and testing. Eleven teachers (44%) discussed challenges and opportunities relating to the physical learning space, for instance concerns regarding the number students in the one small area, and advantages afforded by flexible learning spaces in their schools. Some teachers identified issues related to using the app, such as being able to recommend the right tools to students, but teachers also recognised the way the app enabled students to "make something that they may not have been able to make if we used cardboard, or foil, or whatever". Teachers felt the project itself had helped to form a stronger community of practice through "talking about it in the staff room" and "inspiring each other to take risks". Thirteen (52%) volunteered that they had become more flexible, inquiry-oriented and student-centred in their teaching, with seven (28%) identifying that they had shifted to form learning partnerships with their students. Of the 24 teachers who participated in the interviews, all indicated that they would like to integrate another makerspaces unit into their classes in future.

Limitations

In meeting the study's aims, several limitations are evident. The range of statistical analyses that could be applied across all questionnaires was constrained by the overall small sample size. Also, given the self-selected nature of the sample, it is possible that findings would differ with a larger sample including teachers less willing to engage in professional learning and/or teach in makerspaces. The study's duration (comprising approximately two school terms) was relatively short, providing no scope for follow-up data gathering to determine more enduring changes to practice. Likewise, teachers' participation in the study was mediated by time constraints that included meeting reporting deadlines and curriculum requirements, and by their access to technology resources and infrastructure. Finally, it is possible that the differing size and make-up of different schools could have variably impacted on the beliefs or attitudes of their respective teachers, though there was no evidence found that could directly associate professional learning effects to individual schools.

Discussion and Conclusion

The professional development structured around established pedagogical frameworks (IDEO Design Thinking Model, Papert's Eight Big Ideas) and active learning experiences significantly improved teacher confidence to teach in makerspaces across all three schools. This accords with earlier research that proposes professional learning for makerspaces should provide opportunities for teachers to experience the effect of maker pedagogies and environments (Oliver, 2016a; Paganelli et al., 2017; Purpur, Radniecki, Colegrove, & Klenke, 2016). The study also indicated that the initial professional development phase had a larger positive impact on the makerspaces confidence of teachers who were generally less confident with technology. Moreover, the greater teaching experience of participants who chose to participate in the supplementary online professional development possibly indicates that this form of flexible professional development may be of greatest benefit to teachers who have less recent training in technology-enhanced learning through university-based initial teacher education programs. However, it is equally possible that these teachers had more time to devote to the online component, given their levels of teaching experience.

Teachers from each school identified the benefit of the hands-on, theoretically grounded, socially-oriented and industry facilitated professional development in terms of raising their awareness of makerspaces, developing their technological capabilities, enabling them to collaboratively develop units of work, and helping them to cultivate a better understand maker pedagogies such as inquiry-based, design-based and student-centred learning. Interestingly, these outcomes appear more linked to design thinking than technology use, suggesting that the design processes related to discovery, interpretation, ideation, experimentation, and evolution are transferable beyond the immediate contexts of 3D design and 3D printing. Nonetheless, teachers did voice concerns about potential technology problems and resourcing issues, having technical and pedagogical support from colleagues, how they could best support their K-2 learners through the design process, having enough time for planning and teaching for makerspaces learning, and having adequate support from school executive. Accordingly, there was a drop in teacher enthusiasm to teach in makerspaces after the professional development phase.

However, after the second phase of situated professional learning, teacher enthusiasm significantly increased. Although after implementing their lessons within the three school professional learning community teachers identified that several their pre-implementation concerns were realised, with collegial support, they were able to overcome many of these issues to implement their units, at the same time significantly increasing their confidence and enthusiasm. Several teachers identified improvements in students' design thinking capability, and also how their pedagogy had become more collegial, flexible, inquiry-oriented, student-centred, and student-partnered.

This ecological examination of how active and situated professional learning can influence teacher beliefs and practices has several implications for schools and educational systems. Firstly, the different components of the professional learning all made a crucial contribution to teachers, but in different ways. The initial structured professional development was crucial for developing teacher technological and pedagogical capabilities, and correspondingly their confidence to teaching in makerspaces. The online component was taken up by experienced teachers, who did not have the benefit of recent technologically-focused training from a teacher education program. The extended, situated and collegially-supported professional application phase enabled teachers to overcome apprehensions and increase confidence and enthusiasm. Thus, schools and systems may choose to provide all three elements – structured professional development, supplementary online professional development, and a collegially-oriented implementation phase – in their makerspaces professional learning programs.

Secondly, the findings suggest that the nature of the makerspaces professional learning played a critical role in contributing to the development of teacher capabilities and dispositions. The positive contribution of school-based and inter-school professional learning communities that provided pedagogical and technical support accords with previous research (e.g. Vesicle, Ross & Adams, 2008), as does the value of having teachers experience the constructionist learning environment that they are being encouraged to create (Oliver, 2016a; Paganelli et al., 2017; Purpur, Radniecki, Colegrove, & Klenke, 2016).

Thirdly, the study highlighted that integrating new technologies into the classroom can cause apprehension for teachers, but that teacher concerns can be overcome or even accepted along the path to transforming their pedagogy. Even though the initial professional development was able to improve teacher confidence, it was not able to alleviate all of their pre-implementation concerns. During implementation, many of the impediments surrounding technology integration identified by Kopcha (2012) applied in this study, including problems with access, time, and beliefs (including confidence). But as Mouza (2006) identified, opportunities for active professional learning over an extended duration that included a professional development phase and a situated practice phase, were beneficial. In this study, it significantly increased teacher confidence, and in many cases changed their practice towards more flexible, inquiry-oriented and student-centred pedagogies.

Fourthly, it appears that an institutional and systemic culture that supports teachers and appreciates the required change in learning environments to promote successful makerspace-based teaching is essential for effective implementation. Professional development support is critical to develop teachers' skills and confidence, but also appropriate resources, infrastructure, spaces and time to create effective makerspaces learning environments. A school culture that supports exploration and experimentation, the provision of sufficient resources, and accepts productive failure necessary for design thinking to occur, is fundamental to successful maker-based pedagogies.

Ethics, Conflicts of Interest and Open Data

Approval for undertaking this study was granted by both the researchers' university Ethics Committee, and the New South Wales Department of Education. This study was funded in part by an AusIndustry Innovation Connections Grant, the NSW Department of Education, and Makers Empire

Pty Ltd. The university ethics process adheres with the National Statement on the Ethical Conduct of Human Research (2007), which requires independent and unbiased analysis and reporting of research results. Reliability and validity of findings are reinforced by reporting of primary data. Refer to http://primarymakers.com for a full report on this study, including samples of primary data and extended analysis.

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