Research - Highly immersive virtual reality

What teachers should know about highly immersive virtual reality: Insights from the VR School Study.

Peer reviewed article

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Introduction

Immersive virtual reality (IVR) mediated through a headset has finally arrived for mass consumption. Increasing numbers of children and young people are enjoying the amazing experiences IVR offers during their leisure and school time. It is estimated that more than two million school children have tried Google Expeditions (Charara, 2017) and the Playstation VR has sold in excess of two million gaming units (Webster, 2017). Social media corporation Facebook has invested heavily in virtual reality with its CEO Mark Zuckerberg wanting one billion people living in IVR sometime in the future (ABC news, 2017). Social media platforms are filled with posts from Edtech evangelists spruiking virtual reality as a learning tool accompanied by photos of children wearing headsets (technically known as head mounted displays [HMDs])

The hype surrounding IVR obscures the fact that not all IVR experiences are the same: different hardware and software applications provide very different feelings of immersion in a virtual environment, there are individual variations in reaction to IVR, and the stages of human development can affect the experience. With so much public and educational talk about deploying IVR in schools, it is timely for the teaching profession to ask questions about what is known about the effects of IVR on children and young people, and to begin a dialogue on ethical and practical aspects of using this new technology in classrooms. We address these questions by reviewing existing research and presenting three key insights on embedding highly IVR in classrooms. These insights are drawn from phase 1 of the VR School Study, participatory research being conducted with Callaghan College, Newcastle, Australia.

What is IVR and what do we know about it in relation to children and young people?

There is an extensive literature on desktop computer virtual reality and learning (for a review and a meta-analysis see Mikropoulos & Natsis, 2011, and Merchant et al., 2014). Research has highlighted the learning affordances, or properties of 3D virtual learning environments, that can motivate students and create deeper learning (Dalgarno & Lee, 2010; De Freitas & Veletsianos, 2010). For example, one affordance is the way interaction in a 3D environment can enhance knowledge of spatial tasks. Another affordance is the way a 3D environment can allow a learner to experience or manipulate scale in different ways (for example, you could go on a field trip through the neurons of the human brain) or simulate and manipulate ideas that some learners find abstract such as gravity. Another affordance is the ability of users to experience or practice skills that would otherwise be impossible, impractical or dangerous in the real world (for example, there are simulations which allow astronauts to practice skills in virtual environments before attempting them in space). 3D virtual learning environments also present opportunities for creativity through role play and provide spaces for rehearsal and exploration, experimentation and problem solving. Systematic research reviews on desktop computer virtual reality suggest that there is much technological work on developing 3D virtual learning environments but far less pedagogical research on how to use these effectively for learning, with patchy evidence on the benefits of instruction in VR over time or transfer of learning to other contexts (Mikropoulos & Natsis, 2011; Merchant et al., 2014).

While there are decades of research on desktop VR, the recent commercial availability of VR mediated through a head mounted display (HMD) means that there is a relative paucity in this area, particularly regarding children and young people (0-18 years). While there is no accepted definition of the term immersive virtual reality (IVR), it is possible to describe some of its characteristics. The HMD blocks out most external stimuli, replacing these with the sensory information from a virtual world. IVR is mediated through a HMD that can generate very intense feeling of presence or the subjective impression of actually 'being there' in the virtual world (Slater & Wilbur, 1997). IVR experiences allow for varying degrees of user agency or the ability to act freely in the virtual world. IVR experiences can range from those that allow limited interaction (the person can look around in a 360˚ manner), to those in which a person can navigate or tour an environment in a more mobile way, to highly immersive experiences where a person can exercise a significant degree of agency in the virtual environment through interaction, manipulation, navigation, play and creativity (Southgate, Smith & Cheers, 2016). From life-like simulations to fantasy worlds, IVR 'dramatically extends the range of human experiences way beyond anything that is likely to be encountered in physical reality' (Slater & Sanchez-Vives, 2016, p.6). Highly IVR evokes powerful feelings of presence: that is the virtual place feels real (even if it is a fantasy world) and plausible (even if events in the world could never happen in physical reality) (Slater & Sanchez-Vives, 2016). We define highly IVR as being characterised by embodied, intuitive and agentic interaction in the virtual world. A good way to describe highly IVR is that it's not like watching a movie, it's like being in it, and you can create your own narrative either by yourself, or in a networked environment, with other players.

Manufacturers of IVR hardware and software, such as Oculus Rift ad HTC Vive, stipulate that their technology is not suitable for children under 12-13 years and recommend adult supervision to limit time in IVR and ensure children take frequent breaks. There are no large scale or longitudinal studies on the effects of immersion for children and young people and very few ethical frameworks on conducting IVR research with this population (Southgate, Smith & Scevak, 2017). Early work by Baumgartner et al. (2008) highlighted problems with the ability of children to cognitively and affectively regulate IVR experiences. Using an IVR roller coaster ride, they compared prefrontal brain arousal in adults and children (mean age 8.7 years) finding that children were more susceptible to the impact of audio/visual stimuli and appeared unable to evaluate the experience or inhibit a sense of presence. They conclude that there should be more reluctance to 'expose children to emotional virtual reality stimuli as currently practiced' (Baumgartner et al., 2008, p.11). Segovia and Bailenson (2009) found that exposing primary school aged children to an IVR experience (swimming with Orcas) created a false memory for some children. Children's (8-12 years) ability to distinguish between fantasy from reality was explored in a small-scale experiment which found that 50% of children believed their IVR experience to be real one week after the experiment (Stanford 2015). Another study of twenty children (aged 8-12 years) who played a twenty minute game in IVR found that two children exhibited disrupted ability to detect differences in distances and one child had worsening balance after playing the game (McKie, 2017).

Some research on IVR, with relatively small samples of children and young people, has been conducted in clinical or experimental areas such as pain distraction and social and affective recognition skills with children and youth with autism (Bellani et al., 2011; Didehbani et al., 2016). Research using IVR in schools is scarce. One study used IVR with dance software to teach computational thinking and programming to (mainly) girls in an after-school program (n=8) (Daily et al., 2014) and a summer camp (n=16) (Parmar et al., 2016). An experiment on the influence of character customisation on learning outcomes with middle school students showed positive effects (4M, 32F) (Lin et al, 2017).

To our knowledge there are no studies of the use of highly IVR embedded into the natural setting of the classroom as an extension of teacher practice and for curriculum-aligned student learning. Nor are there highly IVR studies in which teachers are co-researchers. There is immense value in conducting such research as it enhances the credibility and trustworthiness (Creswell & Miller, 2000) of findings and provides insight into how teachers and students grapple with new technologies, solve issues that inevitably arise, and experience their benefits and constraints.

The VR School Study

The VR School project is a mixed method case study on the implementation of IVR in select STEM classrooms at the junior campuses of Callaghan College, Newcastle, Australia. The project received ethics approval from the University of Newcastle Human Ethics Committee (Approval No. H-2017-0229) and the New South Wales Department of Education (SERAP No. 2017396). Phase 1 of the study was conducted in November/December 2017 and focused on the practical, ethical and safety aspects of embedding IVR in classrooms with less emphasis on measuring learning outcomes. Phase 2, will be conducted in 2018 and has a focus on using IVR to enhance learning outcomes. The study was funded under the Digital Literacy School Grants scheme and is guided by the following questions (this article addresses aspects of questions 1, 4 and 5):

1. What happens when students and teachers use IVR for learning?
2. How can the curriculum be tailored to use the affordances of IVR and how can we assess if it enhances learning, including cooperative learning?
3. What are the opportunities and challenges of using the latest IVR technology in low-income school communities?
4. How do students and teachers experience IVR in their classrooms?
5. Given the developmental stages of learners, how can we use this type of technology safely and ethically in schools?

As a form of participatory inquiry (Kemmis & McTaggart, 2008), the research is founded on allowing people to investigate the conditions of the lives for change, including work life. The research team consists of university researchers from the fields of educational sociology and psychology, and computer science, and executive and classroom teachers from the two junior (Years 7-10) campuses of Callaghan College. The College is a low income school community with between 44-48% of students from the lowest socio-economic status (SES) quartile. Fifty four students participated in phase 1 of the study. They were from two Year 8 science classes (n=44, equal gender split) and a Year 9 ICT elective class (n=10, all male).

Three Oculus Rifts (CV1) with Oculus Touch Controllers were set up and networked in designated VR rooms attached to classrooms at each school. The highly IVR used was the Windows 10 version of Minecraft using Oculus Rift with Oculus Touch controllers. The learning activity for the science classes involved groups of three students working together in Minecraft to build a diorama of a plant or plants that demonstrated an understanding of respiration and photosynthesis, and the structure and function of plant parts. Students were asked to research and label these parts and explain the structure and function through a video presentation or virtual guided tour (Figure 1. Student work sample showing full flower [left] and rear-view of flower as cross-section with annotations [right]). The learning task for the ICT class involved researching and building a virtual reality café and explaining the design elements in a similar way.

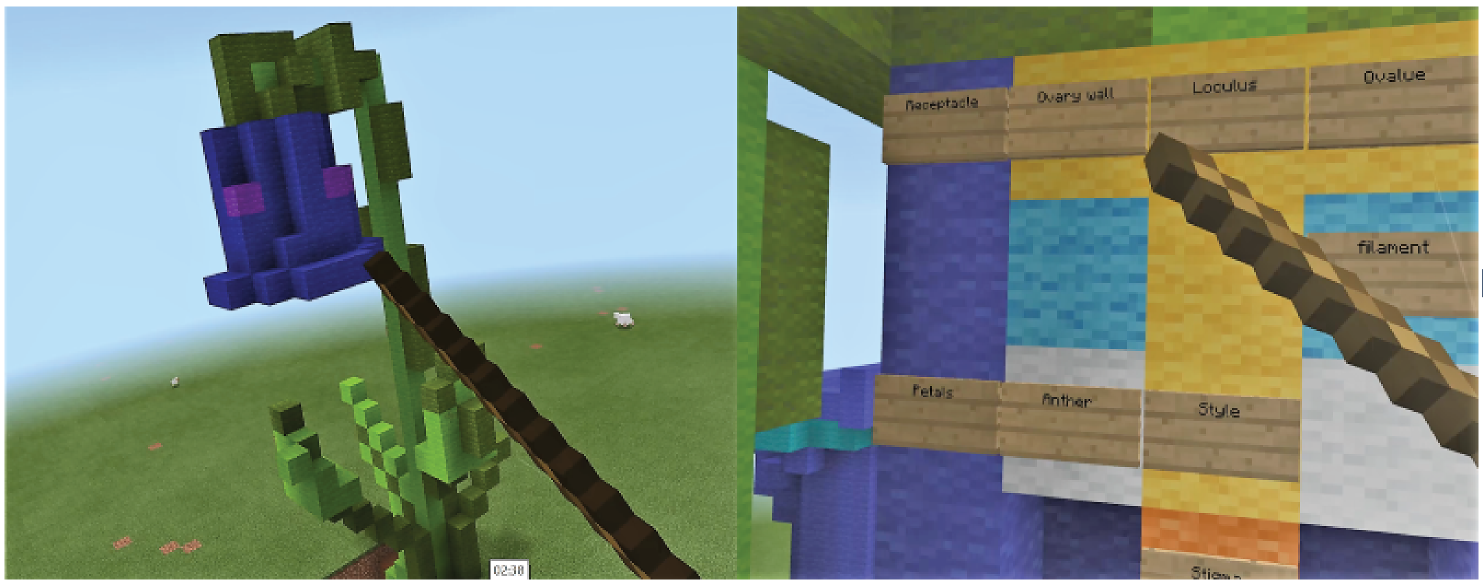

Figure 1. Student work sample showing full flower [left] and rear-view of flower as cross-section with annotations [right]

A range of methods were used to collect data including: observation (25hr 30m); audio (22hr 48m) and video (5hr 39m) recording of students in IVR; screen capture (18hr 9m); student engagement surveys; student work samples which included reflection on the IVR experience and grades; semi-structured student interviews (n=30 participants); and written teacher and student reflections. Analysis was facilitated through an initial circulation of themes and draft refinement process, an approach that emphasised the role of ongoing reflection and dialogue in participatory research (Kemmis & McTaggart, 2008). This approach is situated within a social constructivist paradigm where knowledge production develops through individual and group interaction within specific socio-cultural contexts (Braun & Clarke, 2013). To ensure the credibility of the interpretation and exemplar selection of the three insights presented in this paper, team members evaluated the extent to which the findings were an accurate (valid) representation of the phenomena they are intended to represent (Punch & Oancea, 2004).

Three insights from the VR School Project

Safety is a priority: The research team believe that educational research should not cause discomfort or distress or disrupt the learning of students. As little is known about the effects of highly IVR on young people great caution was taken to identify potential hazards and develop strategies and resources to address these. It took almost a year to develop an initial set of resources and strategies for the institutional ethics applications and new resources continued to be developed during phase one of the study. In line with manufacturer's advice, no student under the age of 13 took part in the study. As highly IVR is a relative new commercial technology, we had no way of knowing if students and their guardians had previous experience of it or knowledge about it. Therefore, the research invitation pack distributed to guardians contained an information sheet and a health and safety survey. The information statement had a photo of a student in the Oculus Rift HMD and a plain English explanation about IVR and potential risks including cybersickness (a type of motion sickness).

There is no standardised way to predict if a person will get cybersick in IVR although motion sickness questionnaires may be useful. Two studies using HMDs have suggested that adult females might be more susceptible than adult males (Allen et al., 2016; Munafo, Diedrick & Stoffregen, 2017). As the evidence base in this area is nascent, we took a cautious approach and developed a one-page health and safety survey as an adjunct to the information statement. The survey was designed so that guardians, with their child, could reflect on the likelihood of getting cybersick in IVR and as an evaluative 'screening' tool to identify students who might be susceptible to cybersickness based on previous experience of IVR. The survey included a slightly modified version of the Motion Sickness Susceptibility Questionnaire Short-form (MSSQ-Short) (Golding, 2006). The survey listed serious conditions (for example, heart condition, epileptic seizure) specified as potentially harmful in the Oculus Rift Health and Safety guidelines. The survey was effective in identifying previous experience of IVR associated with cybersickness and in assisting with informed judgment about the degree to which students might become cybersick. Of the eligible students who participated in phase 1 of the research, one self-screened out of the study before it commenced.

In addition, a teacher safety script and a classroom poster, 'Be VR Aware' (Figure 2) were developed to educate students about safety in IVR and cybersickness. These safety measures were supplemented by the researcher, and occasionally students, acting as 'spotters'. This role involved monitoring students to ensure they did not spend more than 15 minutes in highly IVR, collide with people or objects, or feel ill. A decision was also made that highly IVR would not be part of any lesson timetabled at the end of the school day; this would mitigate any potential for the risk of a student feeling cybersick and then having to make their way home.

Figure 2. 'Be VR Aware' classroom poster

The effectiveness of these strategies and resources was evident in only four observed cases of cybersickness which did not interfere with students attending their next lesson. Students themselves developed good awareness of cybersickness, monitoring themselves and taking off the HMD at first signs. Awareness of cybersickness as an important issue when using IVR is captured in the following student reflection:

> ‘The only negative that I have found is that not everyone can use VR, for people get a headache or stomach, symptoms of car/sea sickness. If we are looking towards the future of learning we need something versatile that all students can harness the full potential of and something that can help them reach their full potential'.
>
> ‘Our virtual reality tasks are entertaining and more engaging than any other normal science class, although while engaging in this task I have motion sickness which causes me to finish earlier than I normally would. There aren’t really any downsides apart from motion sickness'.

There were/are significant technical issues to resolve

There were significant technical issues that required attention during phase 1 of the study, some of which are ongoing. Firstly fitting the study into the timetable and finding an appropriate space to set up the equipment proved difficult. The tracking systems of IVR require space that can allow body movement. Traditional classrooms often do not have enough space for this. In order to set up three networked Oculus Rifts the team needed to find spaces attached to classrooms so that the teacher could easily move between the VR room and the classroom. On one campus the VR room was a storeroom measuring approximately 4 x 3m (Figure 3) and at the other school it was a former preparation area off a science lab measuring approximately 5m x 5m.

Figure 3: The VR room at one school

This set up did have limitations, in that teachers could not always supervise what was happening in the VR room. This role fell primarily to the university researcher although sometimes students took on the role of safety ‘spotter’. Moreover, the teachers spent considerable time in developing a series of ‘work-arounds’ to enable the project’s success. Each school encountered different problems with creating the various external accounts required to update, validate and run a networked version of Minecraft with the Oculus Rift. While it is understandable that the state education department enforce restrictions on internet access this did present a significant barrier for the project. Considerable teacher and researcher time was spent resolving technical glitches such as the software ‘freezing’ or failures in the tracking system. These glitches impacted on student time spent in IVR and presented difficulties in accounting for exposure to IVR to evaluate its effect on learning.

Time for play is vital when using experiential technology for learning

There are decades of research on the benefits of play in early childhood (for example see Roskos, 2017). While there is relatively less research on how play can facilitate learning for adolescents, there is increasing scholarly interest in serious computer games, maker culture and Minecraft for education (Nebel, Schneider & Rey, 2016; Pusey & Pusey, 2016; Southgate, Budd & Smith, 2017). Duncan (2016) captures the importance of play when he states, 'Play is foundational to community, culture, individual development and freedom' (pp.37-38). Caillois (2001/1957) describes play as having two qualities, paidia and ludus. Paidia is the type of spontaneous, exploratory, highly imaginative play often enacted by children. Ludus involves play that is more controlled or directed according to predetermined rules or goals.

Being embodied in a virtual world is an affecting experience. Through controllers that mimic gestural interface, students could use their virtual hands to interact with virtual objects and agents (characters) in fun and imaginative ways. Minecraft VR, which lends itself to autonomy of action and creativity, is a perfect playground for paidia. Students marvelled at their ability to perform fantastical feats such as flying, building monumental structures and jumping off these together, digging deep caverns and diving into lakes. The following except from a recording of a boy in IVR during the Year 9 ICT class illustrates the imagination and joy of free play that most students derived from their IVR experiences:

> 'Horsey (speaking to a horse in Minecraft). I will fly. Oh my god. I am heli-carrying a horse (helicoptering a horse through the air). Look at him! I grabbed the lead and started flying and basically my horse started comin with me. Der da der da der da (singing the Lone Ranger tune). It (the horse) is running in air, it's funny. I think I'm the first ever in the world to ever heli-carry a horse in VR'.

IVR is a deeply experiential technology: developing an understanding of what is possible requires time for embodied familiarisation and experimentation and for overcoming the initial affective 'rush' of being able to do the incredible like heli-carrying a horse. One Year 8 student described his IVR experience as 'psychedelic' in its otherworldliness. Another stated, 'I am a god in VR' and went on to explain to his friends the immense freedom he felt in the virtual environment. Students needed time to play in IVR to emerge from the novelty stage to familiarise themselves with its affordances and consider how these might be used in learning tasks. Regrettably, curriculum constraints did not allow most students or teachers enough time for free play or paidia. This type of play time is required for students and teachers to explore the affordances of IVR and experiment with applications for learning. There were some instances where students creatively engaged fully with the affordances of IVR, and although rare, their imaginative work and playfulness illustrated the educative potential of the technology. For example, one Year 8 group decided on a unique way to conduct their virtual tour of their plants:

> Researcher: So you just built some amazing tulips and a sunflower in Minecraft....
> Boy: So instead of making trees we decided to have all different coloured (flowers)
> Girl 1: And we're now working on a rollercoaster going around all, so you can actually ride around and all that
> Girl 2: Yeah and then see the signs (annotations on the flower parts).
> Boy: So you feel like a bee and all that. (Student interview, 22/11/17)

As this example demonstrates, playfulness can have an important role in motivating older students and nurturing creativity. At present, it is difficult for the very structured, and some would argue overcrowded curriculum, to accommodate play for learning for high school students. However, play is vital for learners of all ages, especially when exploring and mastering new and experiential technologies.

Discussion

Research on highly IVR for education is nascent and studies on its integration into schools are only just emerging. Distinguishing between types of IVR is vital: some IVR allows for a relatively bounded and static experience (you can look around and take in the scenery and what is going on), while other modes allow for a more fully realised agentic experience (in Minecraft VR you can embody an avatar and fully interact in the world through manipulation, navigation and creation).

Developmentally, it is important to understand how different types of IVR experiences might affect learners. The small but telling literature on children's inability to cognitively regulate the intensity of the experience and the phenomenon of false memory for young children who have experienced IVR, indicates that a cautious approach to the technology must prevail. Furthermore, there are no long term studies on the effects of immersion on children and young people. The age limits that manufacturers of IVR put on the use of their equipment should be heeded until longitudinal and large-scale research is undertaken. There is a literature on cybersickness from VR and this points to a need to implement strategies to educate on and mitigate the risk; this was a key element of phase 1 of the VR School Research project. Cybersickness is a very unpleasant experience and if it occurs during school time it will adversely affect a student's well-being and their ability to learn.

It is unsurprising that there were complicated technical issues to resolve when integrating this new technology into classrooms. Technical trouble shooting with IVR required considerable depth of teacher expertise and time during phase 1 of the project. Moreover, the architecture of schools, built as they are for an industrial age, proved a key obstacle in implementing the research. It took time to locate rooms that were attached to classrooms and were of a size to set up the equipment to allow reasonable space for fully tracked movement. Even if we had located a large enough classroom to set up the equipment, the issue of teacher supervision for students in highly IVR presented a practical challenge. It is not reasonable to expect teachers to spend all the lesson looking out for the safety of students in IVR. Complex issues of safety and supervision will need to be resolved if IVR is to become a fixture in classrooms.

To borrow a phrase from a student, findings from the study highlighted the importance of 'playing around in VR for big kids'. Students needed time to familiarise themselves with the equipment, the affordances of the technology, and grow accustomed to the intensity of human virtuality as an embodied experience before attempting to undertake the learning tasks. Teachers also need time to explore the learning affordances of highly IVR. Riding a virtual rollercoaster as a bee with your friends, while guiding the teacher on a tour of the gigantic flowers you have all made and explaining its many parts and functions, is a very different experience to giving a PowerPoint presentation. Likewise, taking your teacher on a tour of an enormous plant with a hollow capillary system that you can all fly through while heli-carrying your pet horse is different from building and presenting a traditional diorama. Leveraging these affordances for learning and fun may be a pedagogical challenge but it is certainly one, we would argue, that is worthy of curriculum and teacher time.

Conclusion

The age of immersive learning has arrived. It will take university-researchers working collaboratively with teacher-researchers to understand how highly IVR can be safely and effectively integrated into real classrooms. Even though our research on the early implementation of IVR has been slow, difficult and sometime unpredictable, we hope that the scholarship and resources it produces will have value for Australian schooling and beyond. Jaron Lanier (cited in Slater & Sanchez-Vives, 2016, p. 2), one of the founders of VR remarked that virtual environments offers an 'infinity of possibility (to)…give us this sense of being able to be who we are without limitations; for our imagination to become objective and (be) shared with other people'. This is the tantalising possibility of highly IVR for pedagogy and learning.

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Visual literacy skills for STEAM innovation

'The greatest scientists are artists as well' - Albert Einstein

Kylie Lawrence, one of three teacher librarians at Hunter Valley Grammar School, explores motives and opportunities for incorporating visual literacy in STEAM learning.

Overview

Visual literacy skills play a vital role in enhancing learning and innovation. Why? Because the digital world is a visual world. To construct knowledge and to innovate, we must be able to visualise since most information is initially processed through our eyes. As STEAM specialist, Kate Mason (2016) argues, ?visual literacy is a mode of thinking that helps us understand and navigate the world around us and is a vital tool in an increasingly visual and digital age?.

Globally, the rise of visual content reflects our physiological thirst for imagery and visual knowledge. In schools, the need for visual assets in teaching continues to transform the educational landscape, with students using images, infographics, video-based instruction, flowcharts, drawings, models, visual programming languages, and virtual reality apps to support learning across all disciplines. As a result, it is necessary for educators to rethink traditional understandings of literacy.

Literacy, visual literacy and STEAM

NSW Education Standards Authority (NESA) and Australian Curriculum Assessment and Reporting Authority (ACARA) recognise the multimodal nature of literacy. As a general capability, literacy supports the need for students to develop the knowledge and skills to competently understand and create written, visual and digital forms of expression (NESA, Science and Technology K-6 Syllabus, 2017, p. 40).

Visual literacy, like visual-spatial thinking, is also multifaceted and develops from the way in which we observe our world visually (Gardner, 2011). Research supports the link between early development of visual-spatial abilities and STEM/STEAM innovation (Lubinski, 2010). Thinking and communicating visually can stimulate critical and creative thinking in any discipline. It is essential for conceptual understanding, spatial reasoning, ideating, rapid visualisation, divergent thinking, problem solving and expressing ideas (Tytler, 2016).

A wide range of outcomes and skills across the curriculum (K-10) support the development of these valuable skills. In the new Science and Technology K-6 Syllabus, both working scientifically and the design and production elements require students to communicate visually. Key terms ? including draw, sketch, generate ideas, represent and model ? provide a plethora of opportunities to foster visual literacy skills.

> ?Drawing is not just about representation, it's about thinking. Trying to understand what you are looking at? The brain sends a signal to the hand and the hand sends one back and there is an endless conversation between them? (Milton Glaser, 2008).

Learning opportunities to develop visual literacy skills for STEAM innovation

In my experience, teachers do not need to be expert drawers or designers to provide students with these learning opportunities. Simply reinforcing spatial language can be a powerful way to improve visual literacy competency in STEAM. Encouraging students to use explicit spatial terms and gestures in everyday lessons, across disciplines, supports visual-spatial ability. Research has shown that focusing on the names of shapes, dimensions, features and relative position of people and objects during everyday activities helps improve visual problem solving skills (Lubinski, 2010).

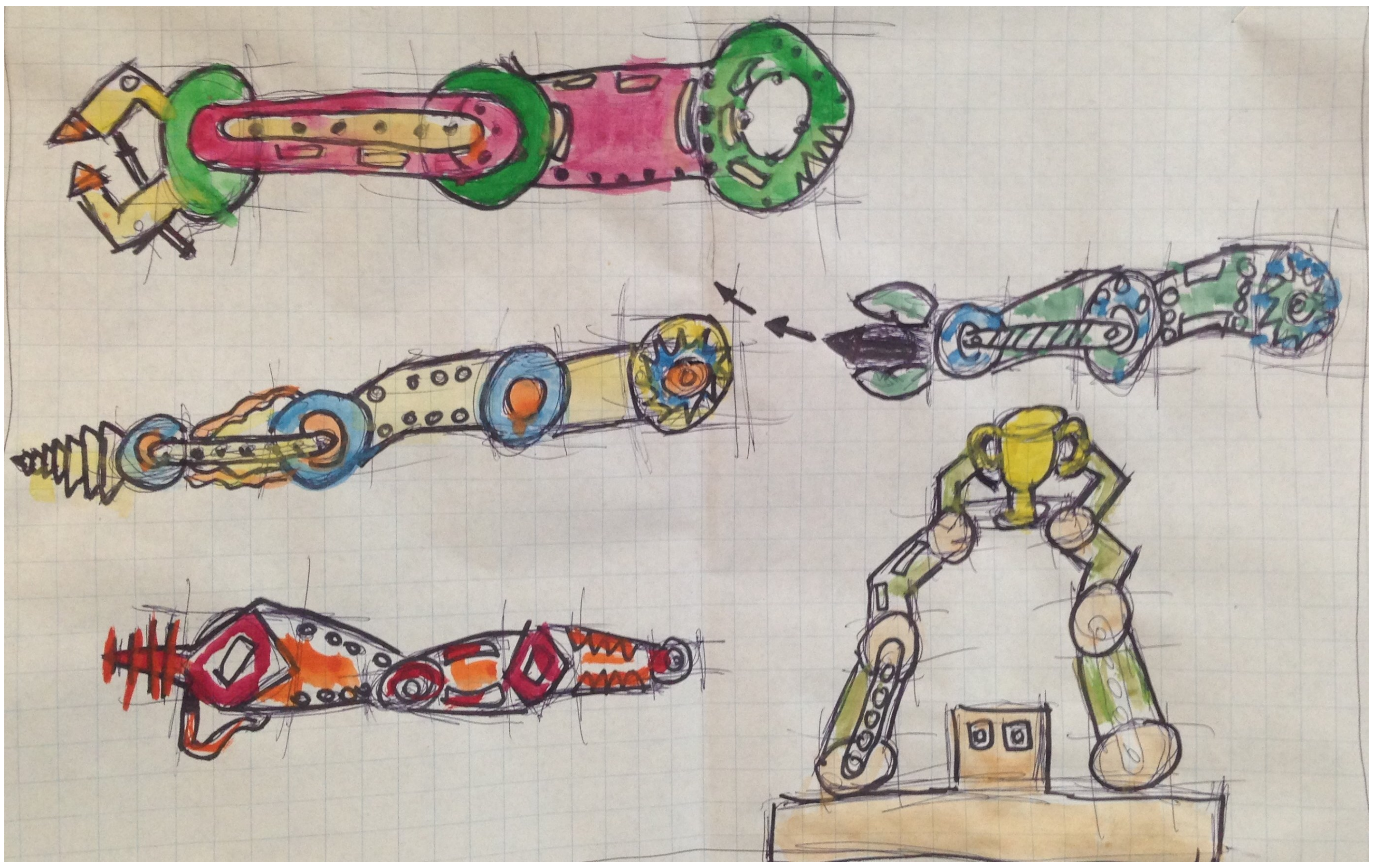
Short instructional videos could also be used to guide students through a series of visualisation exercises for design and production. While professional design skills are not essential, for best practice, teachers do need to:

- be expert collaborators, willing to reach out and partner with other teachers, specialists and professionals to maximise learning opportunities for their students.
- clearly define the success criteria for students
- guide the design process to ensure acquiring the skill further enhances the process of inquiry and learning
- value, document and showcase visual assets produced during the process, as evidence of thinking (for example, rough drawings, note taking).

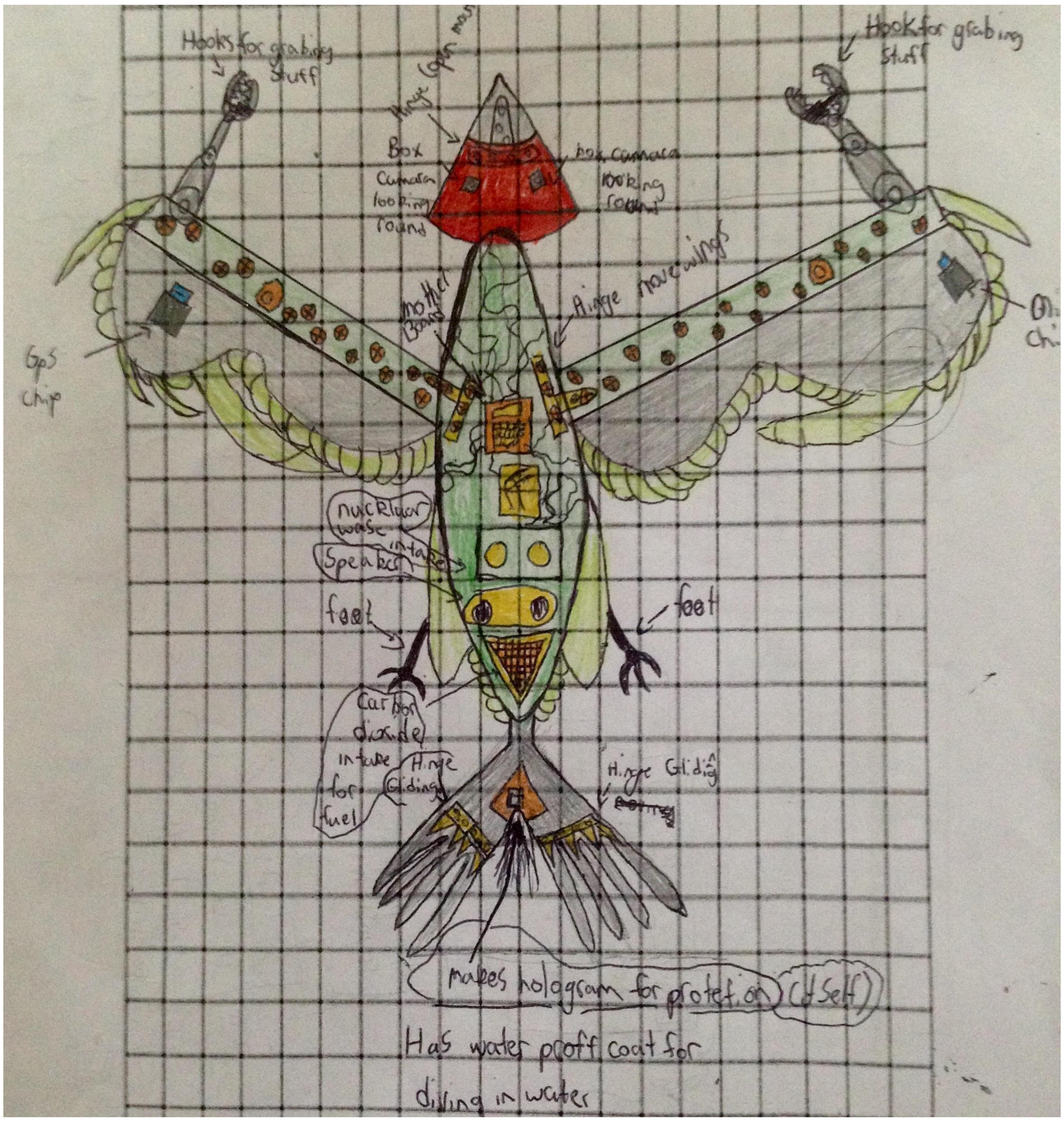
Drawing in maths, technology and science: a Year 4 STEAM unit

At Hunter Valley Grammar School, the focus is on collaboration and innovative practice. Teacher librarians are timetabled to meet weekly with classroom teachers from each year group. From this practice emerged a collaborative STEAM unit with three Year 4 teachers and an industrial designer in which students drew their own robotic creature, detailing its technology/operating systems.

The class had previously been studying ?Mechanica? by Lance Balchin as their English text. Videos on How to draw circles/robot arm (6 min 35 secs) and How to draw an insect machine (14 min 44 secs) from Mr Lawrence were used to model drawing techniques for ideation. Students were required to use a draft and reflection process before applying their knowledge and skills in an assessment task (in-class). Their annotations and use of symbolism were documented in a T-chart, where students compared the function of the human systems to the robotic systems represented in their designs. The T-charts highlighted the detail and functional thought evident in their final designs. Student engagement was exceptional, as evidenced by the students? final submissions:



Year 4 student work sample: Robot arms



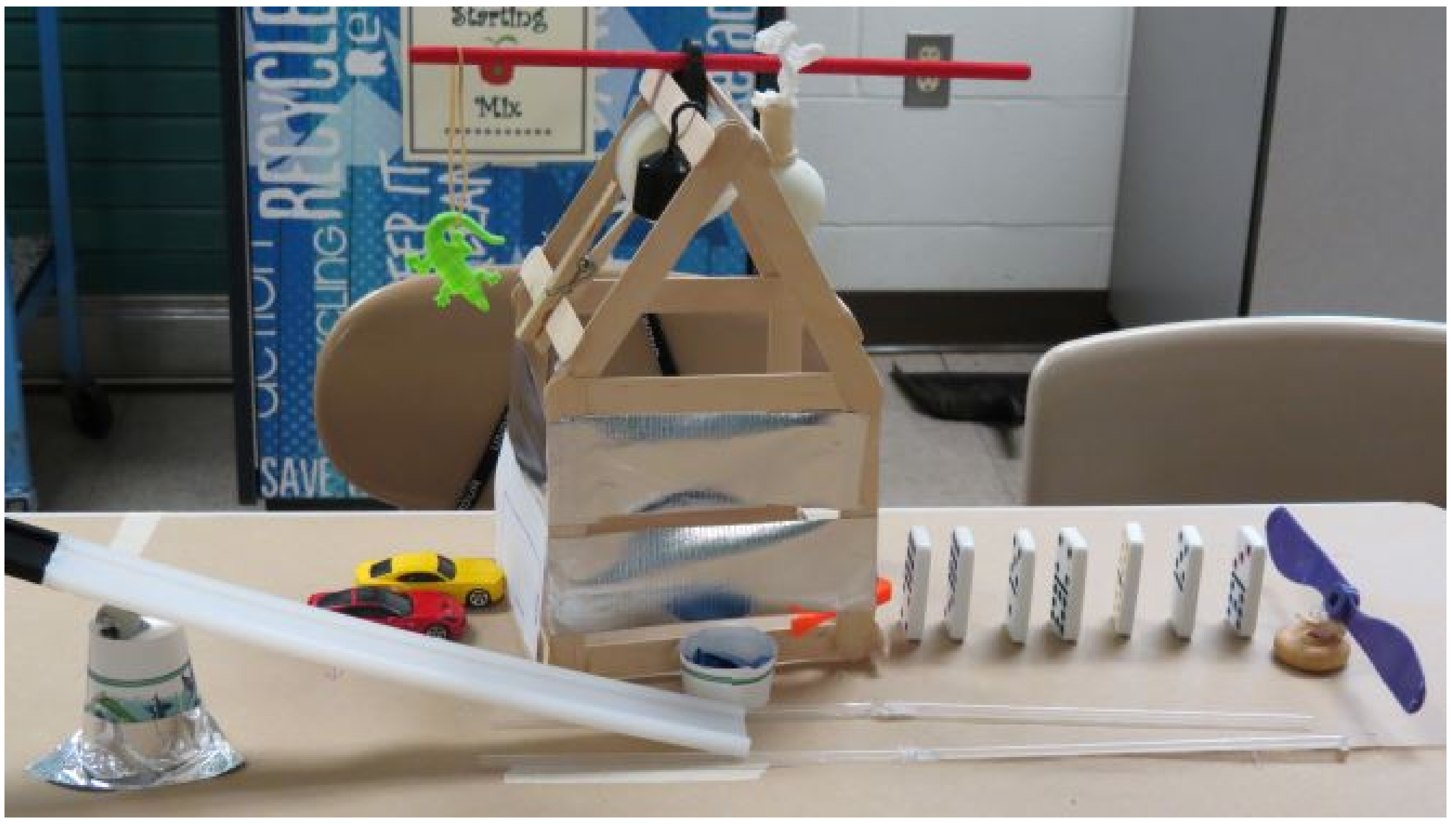
Year 4 student work sample: Robotic creature

Designers, engineers, scientists and mathematicians encourage sketching multiple iterations of ideas. For example, the video on How drawing is used for maths and science by Sir Roger Penrose (3 min 51 secs) from The Big Draw explains how drawing can represent complex mathematical and scientific equations. In our Year 4 task, it was important for students to forget the pretty endpoint of a picture, allowing them to focus instead on visual problem solving and the function of their conceptual ideas. Thinking on paper (and via computer-aided design programs) facilitates the process of manipulating imagery in the mind. This method provides a powerful opportunity to explore how an idea may work in reality.

Rube Goldberg machines

Exciting integrated STEAM units, like NESA's Stage 3 Rube Goldberg invention activity, captivate students? imagination and encourage visual thinking. They also lend themselves to a see, think, wonder approach to learning. As part of NESA?s sample activity, students ?draw a plan of a Rube Goldberg invention that will fit the criteria. For example, at least three transfers of energy. This design plan should indicate materials required, lengths, heights, positions, and angles of placement? (NESA, 2017).

The activity is designed to help students understand forces and the transfer of energy. Targeted outcomes are clearly outlined. This is an excellent, complete resource for teachers, which also offers options for differentiation. The activity could also be broken down for Stage 2 students by creating simpler, mini design thinking challenges.



Student work sample: a Rube Goldberg machine. Copyright U.S. Army CERDEC (?CERDEC Math and Science Summer Camp 2014 - STEM in the Movies?, licensed under a Creative Commons Attribution 2.0 Generic [CC BY 2.0]) and NESA.

Traditionally, a Rube Goldberg invention also tells a story. The associated narrative is often comical and dramatic, adding a dynamic literacy element to the project. Additional resources, for Stage 2 learners and up, can be sourced via the Rube Goldberg website, which offers quality teaching resources and hands-on STEAM ideas.

Alternatively, visually rich digital applications like Algodoo could be used to visualise a Rube Goldberg machine. Recommended for Stage 3 and up, Algodoo is a free desktop application (the paid version is for iPads) that offers an interactive multiphysics playground. Simulations with fluid, pulleys, hinges and motors are endless, and parameters such as gravity and friction can be

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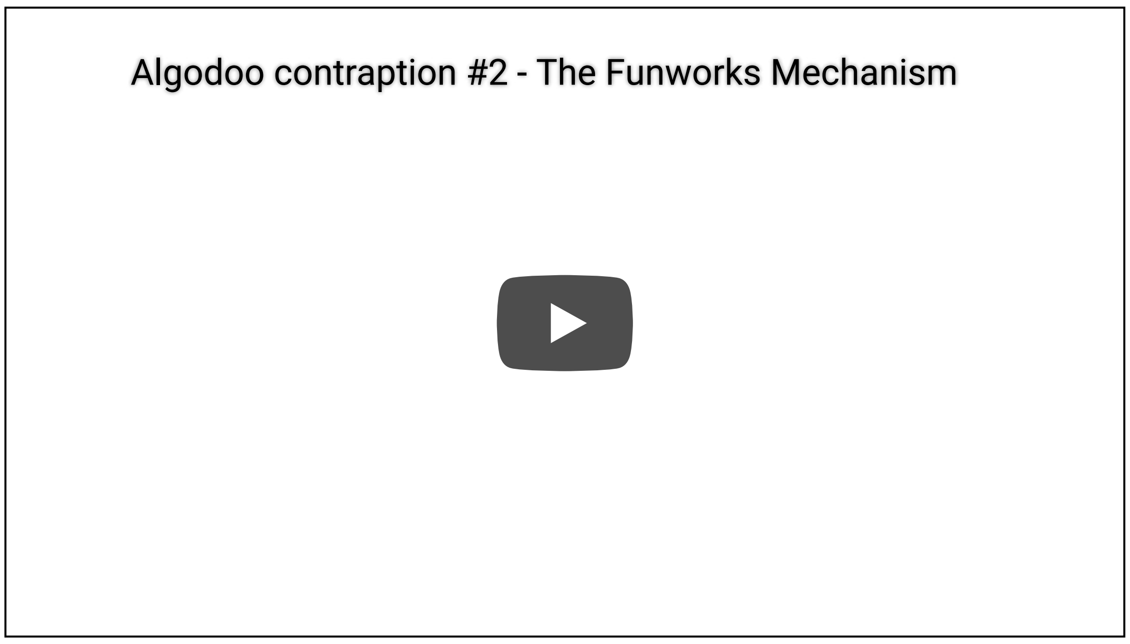
explored. Algodoo is also a great tool for encouraging reluctant or less confident students to get hands on. Our students find it highly engaging, and are often overheard in the library saying ? watch this!' or ?how can I do that?' They enjoy peer tutoring and demonstrating their STEAM knowledge through the application?s amazing creations.

The video Algodoo contraption #2 - The Funworks Mechanism (5 min 55 secs) from PixelCortex offers an example of a Rube Goldberg contraption designed in Algodoo:



Re-Solve: Mathematics by Inquiry project

Programs like re-Solve: Mathematics by Inquiry (K-10), an initiative of the Australian Academy of Science and the Australian Association of Mathematics Teachers, successfully showcase how inquiry and visual thinking practices can help students apply maths strategies to real-world scenarios. In-depth units, such as Shape: Shadows for Stage 1, are provided for each year level. These free materials include classroom resources to support inquiry-based learning in mathematics, special topics for deeper inquiry with a STEM focus or authentic application, and professional learning modules. Rich opportunities are presented for investigating concepts through visual, physical, graphical and symbolic representations, such as in the Years 5-10 special topic, Bringing the real world into algebra.

Conclusion

Ultimately, visual literacy offers a wide spectrum of opportunities to enhance STEAM-based learning. Imagery truly is universal, and through acknowledging and valuing the potential of visual literacy across STEAM related areas, we can equip our students with the tools they need to mine their imaginations for innovation.

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Inside the Google for Education Certified Innovator program

Garreth Wigg, Student Innovation, ICT and Administration Coordinator at St Gregory's Primary School, Queanbeyan, provides personal insights into the Google for Education Innovation Academy in Sydney and shares his emerging Innovation Project.

The Google for Education Certified Innovator program

The Google for Education Certified Innovator program promotes itself as a unique and highly engaging experience for educators to take their teaching practice to new heights. Successful applicants are 'ambassadors for change who empower other educators and students through a thriving innovation culture within their own classrooms, schools and organisations' (Google for Education Certified Innovator program, 2018). With our school 'going Google' over the last four years - adopting 1:1 Chromebooks in Years 4-6 and transitioning to the Google Cloud Platform - I applied for the Sydney intake in August last year.

The Innovation Academy: Sydney

The program opens with a 3 day Innovation Academy (held, in my case, at the Google headquarters at Pyrmont) where participants undertake an intensive program to plan their Innovation Projects. Over the following year, innovators work alongside a dedicated mentor (a past participant - now Google Certified Innovator), a team coach, and the wider Google community to make their project a reality. Academies are offered by Google in various cities around the world each year. To gain entry into a 2018 intake, teachers must:

- undertake Google Certified Educator Level 2 certification (online training and exam)
- complete an online application form
- film a 90 second innovation video, outlining a meaningful challenge in education and explaining why they are suited to tackling it
- submit a vision video demonstrating their commitment to the program values: 'transform, advocate and grow'.

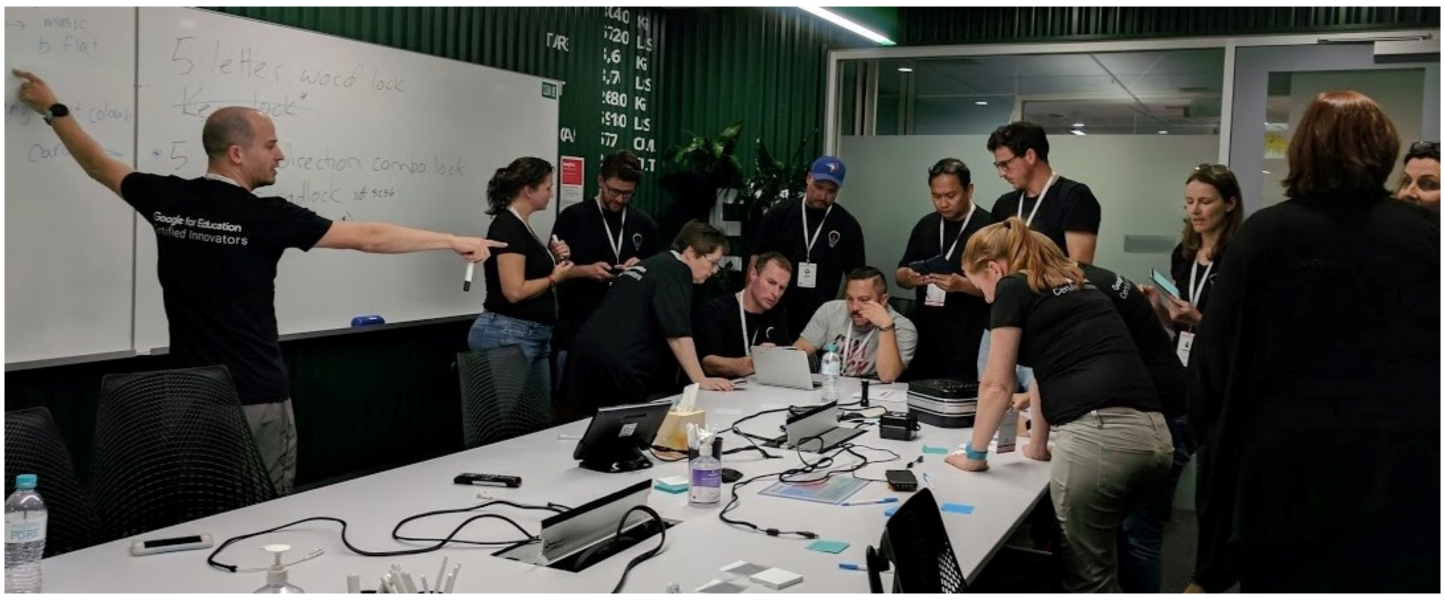
Snapshot of The Google for Education Certified Innovator program

At the Innovation Academy, time was spent developing our own Innovation Projects, undertaking team tasks, participating in 'spark' sessions, and learning about Google products. Project planning used aspects of design thinking (which I have continued to use with staff in professional learning workshops and students in my STEM class). The facilitators for this task were engaging, inspirational and knew their craft. Most importantly, they contextualised the design thinking process for teachers. The focus here was to empathise, define, ideate, prototype and test. This allowed participants' projects to evolve with careful consideration through various feedback approaches, robust questioning techniques and careful consideration. The strong focus on failure and its importance was motivating. There were broad opportunities to collaborate and seek feedback from peers, team mentors and the session facilitators.

Working on our Innovation Projects using the design thinking process: discovery, interpretation, ideation, experimentation and evolution

The facilitators included Google and non-Google staff, with strong teaching experience from around the world. Each presented a tightly crafted 20 minute 'spark' session, outlining an innovative aspect of their professional career that highlighted student, staff or community engagement. The stories, tips and resources they shared were funny, salient, challenging, inspiring and uplifting.

There were also creative team-building exercises. The Breakout EDU session was my first experience with the resource, which has now become a go-to for staff meetings and class activities within my school. There was even a 'greatest race' around parts of the Sydney CBD that helped bring people together in a fun, shared experience. We worked in different groups, collaborating with new people and developing our professional network, while enjoying the camaraderie of working with like-minded educators.



Exploration and collaboration with Breakout EDU

The Innovation Project

Emerging from the Innovation Academy are participants' Innovation Projects, which are intended to 'drive change in education, impact educators and students, and be documented for other educators to follow' (Google for Education Certified Innovator program, 2018). The Innovation Project Directory contains examples of projects that participants are currently developing.

Since participating in the Sydney Academy 8 months ago, my original Innovation Project has evolved into something completely different. Initially, my idea was to create a web-based outreach program to connect school communities and classrooms that would allow students separated by vast distances to learn and work together. Teachers would also devise, prepare and teach together. The collaborative potential of G Suite products, such as Hangouts, Docs and Slides, Classroom and YouTube, would have made this possible. To produce something worthwhile, I envisaged developing free, multi-modal resource templates and sample units of work linked to the curriculum. With advice and feedback from peers, these resources would contain detailed information and support differentiation, inquiry and project-based learning.

However, as the Certified Innovator program emphasises, the ability to 'pivot' with an idea is crucial. Not long after the Innovation Academy, I began finding resources that matched my vision. After a small period of deflation, an alternative approach surfaced - with an opportunity to facilitate meaningful, accessible, high quality professional learning experiences for teachers. This is how The INNovators Network was born: a platform for enjoyable, affordable and engaging professional development, comprising an online community and a podcast, co-hosted with Luke Mooney. While the project is still in its early stages, our mission includes a strong focus on positive participant experiences and utilising technology to share ideas and resources freely.

Final thoughts

Overall, what is so refreshing about the Google for Education Certified Innovator program is the emphasis on thinking differently, collaborating, and disrupting learning. The program models many of the approaches and mindsets which teachers seek to foster within their classrooms and schools. By giving teachers creative space, within a culture of open and constructive feedback, the

Innovation Academy provides a rare opportunity for teachers to redefine and transform learning for their students. I feel extremely privileged to have attended this event and to be supported by a network of educators who continue to help me innovate and grow professionally. Interested teachers and educational leaders can view the remaining Innovation Academies for 2018 or register for updates regarding future intakes.

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