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STEM the Boredom: Engage Students in the Australian Curriculum Using ICT with Problem-Based Learning and Assessment

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Abstract The well-being of modern economies and societies is increasingly requiring citizens to possess capabilities in integrating knowledge and skills in science, technology, engineering and science to solve problems. However, by the end of schooling, the majority of Australian students show little interest in these discipline areas and have no plans to continue study or work in them; many refer to these disciplines as boring. Further, they typically have little experience in integrating knowledge and skills from these disciplines and/or in applying this to solve relevant problems. Therefore, there is a need to engage students with such learning experiences to develop their interest and capabilities, particularly during the early years of secondary schooling. This is not easy for teachers to respond to, but with the support of modern digital technologies and the new Australian curriculum, the potential is expanded and the challenge is more readily achievable. However, appropriate pedagogies need to be supported that include more authentic approaches to assessment. Learning activities need to support students to integrate knowledge and skills across discipline areas in tackling real problems, and this also needs to be reflected in how students are assessed. In this paper, I will draw on personal experience as a teacher, a review of recent literature, components of the Australian Curriculum, and findings from research projects associated with my University research centre, to argue for, and illustrate how, teachers can orchestrate powerful learning activities to promote an interdisciplinary approach to STEM.

Keywords STEM · ICT · Australian curriculum · Assessment · Integrated learning

I started as a teacher in 1979 specialising in mathematics and science in a secondary school. At the time, these subjects were seen as very specialist and difficult, good for everyone, but not necessarily necessary for most people. In fact, often adults would comment that they did not understand most of the content and had not needed to since they left school. I was very familiar with student protestations that "this is boring" and "when are we going to need this?" Therefore, from the beginning, as a teacher, I have always sought ways to make learning activities relevant and engaging. At about the same time, computers started to trickle into schools and so I added computing to my teaching repertoire; initially teaching programming (mainly coding) and then adding general computer literacy, and the use of applications software. Computing was also seen as specialist and difficult, good for everyone, but not necessarily necessary for most people. However, rapidly, it was understood that this technology was going to have an impact on everyone's lives and it both relied on mathematics and science and changed the way these were done and used. A major impact on lives and workplaces was seen through the design and engineering of technologies and related products and services. So moving towards the twenty-first century, increasingly, four knowledge disciplines were connected: Science, Technology, Engineering and Mathematics (STEM) (Ritz and Fan 2015).

The present and future need for STEM knowledge and skills to progress our society has almost become a mantra

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over the past few years (e.g. World Economic Forum 2016; Chubb 2015; The Australian Industry Group 2015). Almost weekly news items herald the need for STEM graduates from schools and tertiary institutions, the lack of such graduates, the economic benefits, both to individuals and to society, of having such knowledge and skills, and what our education system needs to do to respond (e.g. World Economic Forum 2016). Regularly, employers are decrying the paucity of supply of such graduates (e.g. the founders of Atlassian that was recently listed on the US stock exchange Ong 2015). The Australian Productivity Commission (2016, p. 81) reported recently that, "…the availability of people with business and entrepreneurial skills and skills in science, technology, engineering and maths (STEM) seem to be universally accepted as necessary skills for the future".

This paper argues for a change in approach to the development of STEM knowledge and skills in schools that is interdisciplinary, and supported by the use of digital technologies. It starts with an explanation of the nature of STEM knowledge and skills, and their critical role for society and students. Then, the paper explores the problem that most Australian students show little engagement with STEM learning leading to little interest, and few plans to study or work, in associated areas. This is not surprising since few have had significant experience with learning activities that integrate knowledge and skills from these disciplines to solve relevant and interesting problems. This lack of experience provides a rationale for exploring new approaches in school to engage students with such learning experiences, to develop their interest and capabilities, particularly during the early years of primary and secondary schooling. It is suggested that teachers can use information and communications technology (ICT) to support appropriate pedagogies, including authentic assessment, to present STEM learning as more relevant and engaging for all students. I will be drawing on 35 years of professional experience in teaching, personal research and research conducted in the CSaLT (Centre for Schooling and Learning Technologies) of which I am the Director. While the concepts behind STEM are not new, and the desire of many to implement a vision of STEM is not new, this paper is arguing that in general, this vision has not been implemented. It provides some reasons why and some strategies involving ICT in teaching and assessment that could help to implement the vision. The complex relationship between ICT use in schools and the implementation of a STEM approach has to date not been well explored.

From the outset, I am assuming that good teachers always harbour a healthy dissatisfaction with their support for student learning. That is, while they are doing their best and gain satisfaction from the resulting performance of students, they are always looking to do better. They are motivated by two questions related to the purpose of schooling that while debateable by some are accepted by most educators and community members (Productivity Commission 2016; Masters 2013; OECD 2015).

1. Does schooling adequately prepare children for living and working in our society?
2. Does schooling engage children with their range of interests, predispositions and capabilities?

My response to both questions has always been "No", but I am doing my best to achieve these outcomes. With regard to STEM learning, these questions are critical in that we know all children need the knowledge and skills for life in our society, and that many are not adequately engaged to achieve this (Ritz and Fan 2015; Masters 2015). The assumption from this is that STEM must be for all students, not just the university bound, and therefore, a different approach needs to be taken in Australian schools.

What is STEM?

In much of the general discussion about STEM, the impression is that the aim in schools is for STEM (Blackley and Howell 2015). That is, mainly learning in science and maths (separately) with a little technology and engineering stuck between them; an issue highlighted by Sanders (2012) and representing differences in understanding of the meaning of STEM (Ritz and Fan 2015) associated with differing agendas (Blackley and Howell 2015). Then, there are the other areas of the curriculum that feel left out, and so there are discussions about STEAM, where the A for the Arts is inserted (e.g. Myers and Berkowicz 2015b). The legitimate argument is that the Arts add the concepts of design, aesthetics and social connection to the development of STEM products and services. Then, arguments could be mounted for including Humanities and language. In reality, knowledge and skills are not nicely siloed into curriculum areas or subjects, and real life situations call upon an array of interlinked sets of knowledge and skills (World Economic Forum 2016; Ritz and Fan 2015). If STEM is to be of any value, it must be considered as an attempt to represent the interrelatedness of sets of knowledge and skills, in the process of understanding problems or challenges and developing solutions; an approach referred to as integrative STEM education by Sanders (2012). It has no value if it is interpreted as just a call for students to study more mathematics or more science, in isolation (Myers and Berkowicz 2015a). A recent report bluntly stated that "Most existing education systems at all levels provide highly siloed training and continue a number of twentieth century practices that are hindering progress on today's

talent and labour market issues" (World Economic Forum 2016).

Approaches to learning that integrate curriculum disciplines to solve problems, or complete projects, are not new. In Australia, many primary school teachers have implemented such approaches regularly, and at times, in some secondary schools, "middle schooling" approaches to learning have been used that recognise this interrelatedness. My early years of teaching included such approaches with the school philosophy being one of educating the whole student, student-centred teaching … we called it open education. The aim is to meet the needs of students, and this includes preparing them for living and working in modern Australia. Therefore, the requirements that Australian employers have for the capabilities of potential employees need to be considered.

There is a tendency for the leaders of industry, particularly from newer industries, to be critical of schooling in not preparing students for living and working in modern society (Office of the Chief Scientist 2014). For example, Nolan Bushnell, the original founder of the Atari company, complained that schooling was "Mired in the past", and as a result, "so many kids end up after 12 years … at school with all their passion gone … burned up in boredom and process" (Malley 2015). Adding to this problem for some communities, such as in Western Australia, has been that many students and community commentators belittle the value of education when you can get "$100 K for driving a mining truck". Unfortunately, at the same time, companies that design the equipment, training and control systems can not find enough high-quality graphic designers, programmers, systems engineers and project managers. This would seem to indicate that many students are not participating adequately in STEM learning (Ritz and Fan 2015).

Participation in STEM: A Problem

A number of recent reports in Australia have highlighted a problem with the low participation and engagement of students in schools with STEM learning (Masters 2015). A report by The Australian Industry Group (2015), *Progressing STEM Skills in Australia*, claims that in schools participation in science and advanced mathematics is declining and that students underperform, while in the tertiary education sector, participation in STEM-related disciplines is in decline and is low in the vocational sector except for engineering. It goes on to quote a Australian Bureau of Statistics report that jobs requiring STEM skills were growing at about 1.5 times the rate of other areas of employment, and that Australia's performance lags behind comparable countries. Further, it claims that 44 % of employers had "difficulties recruiting STEM qualified" workers due to a "lack of qualifications" (36 %), and a "lack of employability skills and experience" (34 %). This report highlights the problem identified by others such as Ian Chubb (2015), the past Chief Scientist of Australia, that demand for STEM knowledge and skills outstrips supply through the Australian education system. This is particularly highlighted in high-technology areas such as digital technologies with a report by Deloitte Access Economics (2015) finding that during 2013–2014, there were 19,000 net arrivals to Australia of ICT workers to fill key technical capabilities in fields such as software development and programming.

Part of the problem is that students "drop out" of STEM studies as soon as is possible. This is particularly evident in senior secondary enrolments with Kennedy, Lyons and Quinn (2014) highlighting the decline in enrolments in science and mathematics in Australia. Chubb (2015) suggests that solutions to the problem of participation in STEM subjects include:

- the training of teachers in effective teaching practices;
- the fostering of effective partnerships between schools, vocational institutions, universities and professionals;
- ensuring that the skills of STEM graduates meet the demands of employers; and
- promoting community engagement with science and technology.

Why Don't Students Engage with STEM?

Getting students to engage with STEM is more than just being enrolled in a class for an associated subject; it is thinking and acting about the concepts associated with STEM. This is what Myers and Berkowicz (2015a) refer to as a STEM Shift. A government report in the USA suggested that many students were not engaging with STEM learning because by the time, they entered secondary schooling they found it "too challenging, boring and/or uninteresting" (President's Council of Advisors on Science and Technology (PCAST) 2010). Other research has suggested that students, particularly girls, perceive teachers of these subjects to be less attractive and creative (Kessels and Taconis 2012). Further, those such as Masters (2015) suggest that the curriculum is not suitable because it focuses on "substantial bodies of factual and procedural knowledge", is not "cross-disciplinary", does not "promote creativity" and is not collaborative (p. 3). This concern is echoed by the Australian Productivity Commission (2016) that reported, "… the current approaches are not delivering the problem-solving skills needed for technology-rich work environments" (p. 86). This is likely to be the reason why they found "relatively high underemployment of STEM graduates and apparent

underutilisation of STEM skills". Education systems that just focus on more science, maths or technology content do not provide the required, "capacity to apply their skills across a range of fields and different situations" resulting from "a depth and breadth of skills … to deal with the changing nature of the labour market" (p. 84).

Why do many students either "drop out" of STEM or "switch off" in STEM classes? From my experience, some students claim that the content is not relevant to them, or their future plans do not need the content. Some may state that they are 'no good at it' or they do not find it "interesting". Some will say it is "boring". For these latter students, it may be the case that the way it is presented in class does not grab their imagination because perhaps it is too theoretical and passive rather and active (Freeman et al. 2014). No doubt there are many reasons. Whatever the reason, we can and must do better, and I am convinced that ICT can help to achieve this. Not using the technology for its own sake, but using it purposefully with the aim of engaging students with STEM learning.

Using ICT to Support Learning

Digital technologies, or ICT, have evolved into a huge range of flexible and relatively cheap tools, which are increasingly available in all Australian schools. Their use in schools has been the subject of considerable research for the past four decades with the general consensus that they can be used to effectively support better learning environments and activities, particularly to support student-centred learning (e.g. Newhouse 2014; US Department of Education 2013; Stevenson 2013). However, using these technologies is not a new way of teaching, rather it is supporting good teaching to be more effective. At this point, it is important to note that the use of ICT as an instructional technology is not represented by the T in STEM; that T is where knowledge and skills in technologies (including digital technologies) are used as part of the solution of STEM problems (Sanders 2012).

The rapid evolution of digital technologies has been particularly noticeable in the provision of more flexible input and output to support communication; critical to education practice. Also of particular interest to educators has been the evolution in software to be more targeted (e.g. app), online (e.g. cloud), and more affordable. Further, both the software and hardware are more connected with increasingly every digital technology able to be connected to every other. All these trends have led to these technologies being more popular in the general community, as well as in schools. Often teachers feel that because these technologies are popular with students and they use them at home, they should be used at school. Do they need to use new popular technologies? No, but if they have a healthy dissatisfaction for the outcomes of schooling, then they need to consider the options, and the opportunities afforded by these technologies to improve their teaching and the learning experiences they offer students.

Teachers have discovered many ways that ICT can be used to achieve better outcomes, from relieving the tedious, to unlocking the imagination. There are many tedious tasks that are a necessary part of some learning experiences, such as handwriting, drawing graphs, completing calculations and collating data. Often, students can use software applications such as word processors, spreadsheets and calculators to expedite these tasks so that they can more rapidly progress to the more interesting and imaginative tasks. Often, ICT can be used to support those more imaginative components of tasks, even making use of online games (Drigas and Pappas 2015).

Learning and fun are words not often combined in the same sentence by students. While the aim is not to turn schooling into pure entertainment, there is no doubt that often learning can be fun. For example, a class was learning about plagues of the past such as the Spanish flu and Black plague of London. A group of students in the class happened to discover an app called Plague, for their smartphones. The following is how it is advertised.

> Can you infect the world? Plague Inc. is a unique mix of high strategy and terrifyingly realistic simulation… Your pathogen has just infected 'Patient Zero'. Now you must bring about the end of human history by evolving a deadly, global Plague whilst adapting against everything humanity can do to defend itself. (http://www.ndemiccreations.com/en/22-plague-inc).

The students asked their teacher whether they could spend some time in class using the app to model the plagues they had been learning about. At the same time, they learned a lot about virus and bacteria, and geography because they needed this information to design plagues and select environments within which to release them.

ICT can be used to focus attention on some particular aspect of learning, for example, WISE is a web-based inquiry science environment (https://wise.berkeley.edu) that supports students to focus on the inquiry process and outcomes. In fact, ICT could be viewed as the Swiss army knife for learners that almost any age of child can operate, and that extends his/her physical and intellectual capabilities, particularly where it has become "one" with the user.

With the excitement of what can now be accomplished using ICT in schools, there is a temptation to consider that this is now a new way of teaching and learning. I do not believe so. Rather I consider that digital technologies are used, as any technology, to support better teaching and learning by providing a larger range of options. For

example, by the year 2000, digital video became very accessible with the advent of cheaper digital cameras, more easily connected to computers, and editing possible using easy to operate and cheap software such as *iMovie* and *Movie Maker*. Many teachers and students started to incorporate the creation of digital video into learning activities leading to some stating that this was a new way of teaching. However, I recall as a secondary school student making a very short scripted movie with other students in my English class. The teacher borrowed an expensive 16-mm film camera for a day and each group shot their 2 or 3 min movie. A week or so later, the processed films returned for editing that consisted cutting the film with scissors and splicing it together with tape. We were the only class in our year that had this experience and we only did it once. So, the educational idea of students creating movies in English is not new, what is different is that now teachers and students can all do this whenever they see fit. That is, ICT provides the opportunity to do what teachers and students want to do more easily, and more often. It's all about better learning environments and using technology to do better what is known about learning. However, it is generally accepted by researchers there is no direct link between using the technology and getting better learning outcomes (Lei and Zhao 2007). The connection is mediated through the learning environment, and it is the skill of the teacher to create such positive environments (Fraser 1994).

While in general no direct causal link has been found between the particular use of ICT and improvement of associated intended learning outcomes, there is much research that shows teachers how connections can be made through supporting favourable learning environments. For example, in early research in the USA, it was found that scores on achievement tests increased to the 64th percentile for students who used a computer-based instruction system (Mann et al. 1999). In Europe, the use of ICT was associated with improvement in attainment levels of school children between ages 7 and 16 years old in English, science, and design and technology (Biagi and Loi 2013). A meta-analysis report from the UK found that in more than a third of cases improved outcomes were associated with a greater use of ICT (Becta 2006). Another study investigating students' performance in PISA mathematics tests found that in OECD countries, there was a positive correlation between the amount of ICT use and scores attained (Organisation for Economic Co-operation and Development 2005). In each of these and other similar research findings, it is possible to hypothesise how the technology(s) were used to improve the learning environment and support the improved learning outcomes.

An illustration of how ICT may support improved learning is provided by the study by Lei and Zhao (2007) at a secondary school in the USA where all students had their own laptops. They investigated whether the use of the laptops led to improved GPA (Grade Point Average) test scores. Initial analysis indicated that over a year, on average, students who used their laptops for up to about 3 h per day showed progressively larger improvements in GPA. However, further analysis showed that while there were average improvements, some students did not improve, despite using the laptops for the same amount of time as student who did. Using data on the type of use made of the laptops, they suggested that some uses were more "meaningful" uses than others, and these uses were not necessarily the most popular. They suggested that, "…uses that had positive impact on students were those related to specific subject areas and focused on student construction" (p. 284). So while on average the time using the laptops made a difference, the impact on learning depended more on the type of use and how that was connected with the curriculum and supported learning processes. Variations between students depended on the amount of meaningful use.

So, rather than looking for direct links between ICT use and learning, we need to consider the ways in which ICT may be used to enhance the learning environment. A review of the literature suggests a substantial body of evidence that ICT may be used to improve attributes of learning environments associated with (Newhouse 2015): Investigating real problems and data; Building knowledge; Promoting active learning; Supporting authentic assessment; Engaging students by motivation and challenge; Providing tools to increase student productivity; Providing scaffolding to support higher level thinking; Increasing learner independence; Increasing collaboration and cooperation; Tailoring learning to the learner; and Overcoming physical disabilities.

Therefore, it is not what software is used, but how it is used. Sometimes, there are very simple ways in which ICT can be used to improve one or more of these attributes of learning environments. For example, a project I prepared for students concerned with the design of a watering reticulation system for a school lawn aimed to improve the learning environment by investigating a real problem and using real data. Using a spreadsheet template to calculate the cost of all the components needed for a design aimed to improve the learning environment by increasing productivity and motivation. The results were improved designs because students were more likely to change their designs in response to cost analysis from the spreadsheet. Similarly, students could investigate electric circuits using simulation software (e.g. Yenka) in which the aim is to improve the learning environment by investigating real problems, increasing productivity, and through active learning. Students could use brainstorming/concept-mapping software to focus the learning environment on

building knowledge and higher-order thinking, or just to increase productivity. The simple use of tables in a word-processed document to analyse information can be used to support higher-order thinking and knowledge building. Activities to create movies can be undertaken to accommodate varied learning styles, motivation and challenge. WebQuests and Learning Management Systems (e.g. Edmodo, Moodle) may be used to support the learning environment to be more collaborative, allow more student independence, and more authentic assessment.

In planning for the use of ICT, teachers tend to develop more open-ended tasks with ICT used to support some processes and/or sub-tasks. For example, as part of a research project, I observed a teacher and students beginning a project centred on the design of a planet and its place in a solar system (Newhouse et al. 2014). This was introduced with an augmented reality app and an online simulation. Decisions to use ICT with these learning tasks tend to be problem-based or driven (i.e. use the technologies to solve problems), and ideally support problem-based learning. For example, I worked with a teacher and his class on a project in which groups of students designed a new school campus (Newhouse 2004). Students decided when to use ICT with typical use for tasks such as technical drawing, keeping notes, making presentations and analysing survey data.

ICT can be used to support activities that tap into student interests such as sports, movies, music, images, events, and how things work. Real data and technologies are helpful. For example, a TED Talk by Rajiv Maheswaran (2015) that explains how probability modelling is used in NBA basketball coaching could be used with students who are obsessed with the NBA to see how the probability they are learning is used in the real world to organise "pick and roll". Similarly, a movie by Pixar explaining the maths behind the computer-generated images in their movies may spark an interest in some students. There is no shortage of STEM activities that can be enhanced or supported with ICT. I have developed problem-based projects requiring STEM knowledge and skills and supported with ICT under the titles: Design a reticulation system; Set up your own business; Construct a survival shelter; Design wheat silos; A "green" house; Choose a new power station; and Measure river flow. The last on the list was first developed as an introductory calculus activity, at a camp for Year 11 students, to measure the flow of a river. The activity used a local river and the physical equipment that was available near a bridge on the river and had the assistance of a government water authority employee. Later, I developed simulation software of the equipment so that similar activities could be used for other rivers that could not be physically visited.

In summary, the reasons to consider using ICT in schools are to increase relevance and engagement, and to support better teaching based on knowledge about learning. Schooling should have greater relevance to the immediate and future needs of students, and the school curriculum needs to be relevant to twenty-first century Australia. That is, the aim is to better engage diverse groups of learners and base schooling on our knowledge about learning, particularly as pedagogical knowledge evolves. In particular, it is likely that ICT support can be used to better engage children with STEM learning.

Making IT Happen

Increasingly, teachers are finding meaningful ways of using ICT. However, many do not, or they find that the use does not lead to the hoped for learning gains. The problem may be one of orchestration. This is a term used more recently (e.g. Prieto et al. 2015) for what I would term "Making IT happen". It concerns implementing the planned use of ICT. None of the potential benefits of ICT use can be realised without appropriate and skilled implementation. There has been considerable research into implementation that has led to conceptual frameworks and models. Prieto et al. (2015) suggest that there are five key aspects in characterising orchestration.

- Design: the preparation and organisation.
- Management: classroom, time, groups, workflow, etc.
- Awareness: students' learning progress and actions.
- Adaptation: unexpected events, opportunities, student progress.
- Roles: of the teacher and other actors.

Further, there are factors that shape orchestration that are described in terms of theory, pragmatism and synergy.

- Theory: pedagogical beliefs, attitudes and ideas.
- Pragmatism: compliance with curriculum requirements, time constraints, discipline, resources, etc.
- Synergy: how the multiple elements can be aligned to achieve effective learning.

This seems like a lot of theory, whereas in practice, it is relatively intuitive for experienced teachers. I believe that in essence, they follow six basic steps, whether formally or informally (Newhouse and Clarkson 2008).

1. Identify potential.
2. Select appropriate software.
3. Organise access.
4. Select appropriate implementation model.
5. Manage the implementation.
6. Evaluate success.

The starting place is to identify the potential for ICT to enhance learning within the context of the group of students and the required curriculum. However, there is, then, an on-going iterative process of making decisions about how best to implement the application, bringing to bear the best planning and management, and then collecting data on the intended and unintended outcomes.

Curriculum for Twenty-First Century

In planning to implement ICT support for learning, teachers primarily aim to align with the intended curriculum and this can either be an obstacle or an enabler. Where there is a very prescribed curriculum, laying out detailed specific content that may have not been recently updated, this can be an obstacle for teachers aiming to use ICT to support open-ended project or problem-based learning activities. If the curriculum is developed around what students need to live successfully in our "global village", then technological changes should lead to changes to the curriculum content and pedagogy. This should then be an enabler for teachers implementing ICT support for learning. This was the intention of the new Australian Curriculum.

New Australian Curriculum

A new curriculum has been developed in Australia designed to meet the needs of our twenty-first century society (Australian Curriculum, Assessment and Reporting Authority 2013). Australian leaders are aiming to develop a "knowledge-based society built around the innovative, creative and enterprising" use of digital technologies (Australian Workforce and Productivity Agency 2013). Thus, in developing the Australian Curriculum, the intention from the beginning was to entrench the use of ICT in all aspects of the curriculum. Therefore, there are systematic and purposeful references to the use of ICT embedded in all curriculum areas. These are linked to a general ICT capability that, similar to literacy and numeracy, needs to be demonstrated by all students. Finally, there is a digital technologies curriculum subject (part of the Technologies curriculum area) that provides more specific instruction on the use of these technologies (including programming) beyond the general capability.

While, in theory, the new Australian Curriculum purports to enable greater use of ICT, in fact, it still throws up obstacles, particularly for STEM learning. In particular, the structure still tends to put the curriculum areas into silos with minimal links between the science, mathematics and technologies curriculum areas. Teachers would need to do a lot of work to integrate content across the areas for particular learning activities. However, within the areas themselves, the links to ICT use are relatively strong and varied.

In general, the aims of using ICT within the curriculum are primarily to develop capability for living and working in society, and to improve learning outcomes in all areas of the curriculum. It is recognised that digital technologies have complex, varied and complementary roles within the Australian curriculum that could be characterised by four types (Newhouse 2013).

1. *Pedagogical Tools* in all areas of the curriculum, including the STEM curriculum areas (e.g. accessing information, simulations, supporting communication and collaboration).
2. Related to particular *Content* (e.g. calculators in maths and device control in science).
3. *Technical Tools* to support the investigation and design processes in curriculum areas such as technologies and science.
4. The *content/subject for study* in the Digital Technologies subject in the Technologies curriculum area.

The ICT general capability is largely related to the content of curriculum areas and is a minimum requirement for all students. However, such a capability needs to be defined relative to a person, community and the technology available and therefore needs to be interpreted by the teacher for his/her students. In general, ICT capability concerns the development of transferable and useful knowledge (conceptually based) and skills in using ICT to solve problems and facilitate the completion of tasks. As such it includes conceptual knowledge about digital systems (components and operations), their capabilities, limitations, and use in society; skills in using such systems to perform relevant tasks and solve problems; and the development of informed attitudes towards personal and societal use of ICT. Thus, the capability contributes to the T component of STEM. In developing ICT capability, consideration needs to be given to what type of tasks students need now and in the future. Most tasks for which students need ICT capability now are associated with school activities. However, in the future, every student needs a broad ICT capability for workplace tasks that are likely to be many and varied (World Economic Forum 2016), such as in the following examples.

- Checkout at the supermarket—interacting with simple databases and scanning.
- Admin/receptionist—creating documents, entering data into databases or spreadsheets, online communications.
- Self employed "tradie"—creating documents, keeping data records, spreadsheet budgets, online communications, online advertising, online banking including mobile transactions.

- Manufacturing skilled worker—robotic control, data control, accessing design and operation information.
- Services skilled worker (e.g. banking)—online database systems (entry, search and access), online communication systems.
- Healthcare worker (e.g. paramedics)—mobile and online database systems, online communication, device control systems.

While the Australian Curriculum aims to include references to ICT as much as possible in all curriculum areas, the over-riding consideration for teachers should be achieving learning outcomes, i.e. using ICT to solve educational problems. The structure of the ICT general capability does help teachers match the ICT applications they would like to implement with the likely capabilities of students. However, the use of ICT to address educational problems within a curriculum area will not always contribute significantly to ICT capability. For example, the use of Yenka science modelling software with senior secondary students will not, while Millie's MathsHouse with early childhood students may. Despite its limitations, the Australian Curriculum does provide the "hooks" with which to attach ICT use with the curriculum. School systems and teachers can use those hooks to contribute to a systematic and comprehensive development of ICT capability. Sometimes, those hooks may need to be interpreted through the elaborations or understanding the meaning of terminology to guide pedagogy. For example, in the science curriculum, references to multimodal texts assume the use of word processing, audio-visual recording and so on. In science, enquiry processes assume some investigating with ICT and using equipment to conduct experiments (e.g. data logging, virtual equipment). Most areas, including science and mathematics, assume the communicating of ideas in a variety of ways, including digital. In mathematics, as well as the use of calculators, many parts of the curriculum refer to activities such as creating shapes, collecting data and solving problems "with and without digital technologies".

Finally, the Australian Curriculum makes links to Australian Digital Resources that are provided online to schools. This is a good source of ideas, although teachers now have many other sources of ideas from international online sites.

Digital Technologies Subject

The Australian curriculum has a Technologies curriculum area that includes a Digital Technologies subject. This subject is focussed on creating digital solutions and has key concepts underpinning learning: Abstraction; Data Collection, Representation and Interpretation; Problem Specification, Algorithms and Implementation; Digital Systems; and Interactions and Impacts. Abstraction is the process of reducing complexity by generalising from specific examples. Creating digital solutions will require data collection, representation and interpretation, probably at various stages of the problem-solving process. These solutions need the development of specifications and algorithms, and ultimately an implementation. These solutions are implemented on digital systems (hardware, software and networks) that need to take account of interactions with people, digital systems, data and processes, and impacts on individuals and communities. In general, the subject as part of technology education fits well with the problem-solving and integrative nature of STEM learning (Sanders 2012).

The major controversy in the curriculum for digital technologies is around the concept of programming. It has become popular in the community to insist that children should learn "coding". However, programming is not just coding; the latter may be a component of the former (Kafai and Burke 2013). Coding is the sets of instructions for the processor, whereas programming is a form of problem-solving that designs solutions to create software and use data. Program coding on its own does not deliver a digital solution because the system context needs to be considered. Code operates within a software environment (OS, applications and data) and gives instructions to a processor that controls other components. This is operated by a user and may affect that person or others. Computational thinking is a programming approach to problem-solving that includes formulating and deconstructing problems to create representations of solutions suited to digital tools, based on algorithmic thinking and compositional reasoning that uses pattern matching, procedural and recursive thinking. Few will become computer scientists who write code, whereas many will encounter the need for some form of programming, even coding, and all will be users who will critically and constructively examine solution designs, and contribute to the associated decisions. So the focus of activity in the Digital Technologies subject should be on designing and creating digital solutions and will include some programming within a computational thinking framework. Wing (2011) suggests that computational thinking is enhanced by problem analysis, graphical representations and data analysis, algorithm development, programming, and coding.

What vehicle should be used to learn programming? Grover and Pea (2013) suggest a use-modify-create approach using purpose-built tools that are easy to get started with, but still powerful. In particular, students can be introduced through graphical programming environments such as Scratch, or gaming such as Game Maker. Activities can use game design, robotics and emerging

contexts such as e-textiles. The aim is to develop transferable knowledge and skills, not syntax and error messages. For example, concepts such as branching (decision-making) can be introduced using the IF–THEN function in a spreadsheet, or buttons with hyperlinks in a slideshow, or controlling a robot, creating an interactive story or game, or creating a script in Scratch or Snap. Traditionally, programming has been a secondary school elective, but many tools are suitable for earlier levels of schooling with key programming concepts accessible for early schooling to introduce informally as young as possible (Kafai and Burke 2013).

In summary, the Australian curriculum provides some support for teachers in their use of ICT with direct references in their curriculum, and through the ICT general capability and the Digital Technologies subject for primary and some secondary teachers. In general, the ICT general capability represents the minimum requirement of understandings and skills to be discerning users of ICT. The Digital Technologies subject represents what all students should understand, and be able to do with ICT, to contribute creatively and productively in the modern world. It includes the understanding the underlying concepts of devices, systems, software and networks. It is not just a "computer science" curriculum; it includes applied IT focus. The aim is a progression of conceptual understanding and the knowledge and skills in operating and managing ICT systems, to exploit the affordances of ICT while minimising the risks. The curriculum aims to meet the needs of all students whether they want to become doctors and contribute towards the design of a client database, or tradespeople and work with developers to customise mobile billing, or become graphic designers or program coders who create scripts. This is consistent with current employment indicators with, for example, a recent report suggesting that "employment growth for Computer and Mathematical roles is expected to be least pronounced in the Information and Communication Technology sector itself, hinting at the accelerated demand for data analysis skills and ICT literacy across, and uptake of these tools by, other industries." (World Economic Forum 2016).

Why Don't We Do All This?

It is clear that STEM provides opportunities for compelling learning activities and ICT provides the flexible support to implement these effectively. So why is there very limited use in Australian schools? There is a complex set of factors including teacher apathy and/or lack of skills and experience (Stoilescu 2015; Blackley and Howell 2015). Even where teachers want to use ICT with their students, and have the skills and experience, many do not due to lack of support and encouragement (OECD 2015). Sometimes, it is suggested that new graduate teachers are more likely to have the skills and enthusiasm to use the technologies. However, in Australia, it has been identified that there is a high dropout rate amongst new enthusiastic teachers with one reason being that there are too many barriers to implementing high-quality teaching. Barriers include discouragement by conservative peers and managers, administrative workload, and contradictory accountability measures (e.g. keeping students quiet) (Crook et al. 2015).

While there is a complex set of factors why many teachers do not exploit the affordances of ICT to support high-quality STEM learning activities, one stands out; the way in which student achievement is assessed. Assessment is a problem because it drives what teachers and students do more so than anything else, including the curriculum content (Masters 2013). Ideally, we should aim to assess what we want students to learn and be able to do; not just what they can write on paper. This problem has been the focus of a lot of our research in the Centre for Schooling and Learning Technologies (CSaLT). We see digital forms of assessment as part of the solution, whether these are portfolios, production exams, performance tests, or digitally recorded performances. This has resulted in the investigation of the potential of digital forms of assessment with students in senior secondary courses in Western Australia, in particular: Engineering Studies; Applied Information Technology; Physical Education Studies; Italian Studies; Visual Art; and Design.

This problem of assessment is recognised by many others. For example, an Australian survey of 400 enterprises (http://www.campusreview.com.au/2015/10/education-system-failing-business-survey/) found that 58 % believed that education is not providing the skills needed to be entrepreneurial and innovative, and 43 % of owners felt their own education had not helped them running their businesses. In a response to the report, an academic typed that he believed that,

> Much of our education system … implicitly privileges written expression at the expense of listening, speaking, reading, seeing & visual expression because nearly all high stakes assessment requires students to write or select MCQ items. … success in business depends much more on all these other ways that people interact with each other, …
>
> At <University> engineering, we have experimented with assessment techniques that bring listening, speaking, reading, seeing & visual expression back into assessment, while still providing solutions that scale economically to large classes. We need more work on this, but the initial results are promising.

This view is perhaps reflected in the results of the National Assessment Program (NAP) of ICT capability in which students of various ages use a computer to complete tasks that assess a reasonably good range of practical knowledge and skills assessed. A report on the results (Australian Curriculum, Assessment and Reporting Authority 2015) states that,

> The performance of Year 10 students had not changed across the three previous NAP – ICT Literacy cycles from 2005 to 2011, though it declined substantially between 2011 and 2014.
> … it does not appear that the overall decline is associated with particular groups of students … or jurisdictions.
> The reasons for the decrease in Year 6 and Year 10 students' ICT literacy levels remain issues for further investigation. (p. xxvii)

There is a range of evidence indicating that students are not acquiring some of the knowledge and skills relevant to modern workplaces. This assessment was unusual in that students used computers; in most, high-stakes assessment in Australia digital technologies is not used.

What is assessed is critical and paper-based "exams" fail to assess higher-order thinking, decision-making, reflection, reasoning and problem-solving (Lin and Dwyer 2006). Further, very few real tasks are done on paper in modern society. We need authentic assessment that aligns with pedagogy and flows from learning. Senior secondary summative assessment tends to be poorly aligned to the intent, objectives/outcomes and content.

Digital Forms of Assessment

In the CSaLT research centre, there has been a focus on using digital technologies to improve the authenticity of assessment, and in particular, research has been conducted around the high-stakes summative assessment for tertiary education entrance. The particular interest was on improving these assessments because there was a suspicion that they had an impact on the whole schooling system. To increase the potential for the research findings to have an influence, it was conducted with the state's curriculum authority and courses where chosen where it was clear that it would be difficult to assess student performance only with pen and paper. For example, the first major project investigated assessment in physical education, engineering, oral language and applied IT. The second major project looked at courses in visual arts and design. All of these courses set out to include a large component of practical work whether through movement, or making something. These large projects received funding through the national competitive research grants scheme, Australian Research Council (ARC) linkage projects. This body of research is offered to illustrate the potential for ICT to be used to refocus summative assessment, to increase its authenticity and thus encourage a more integrated problem-driven approach to the development of STEM knowledge and skills in schools.

The Approach

An approach was developed that was labelled as Digital Forms of Assessment that involved three key components.

1. Digital capture to represent student performance.
2. Online repository for accessibility to markers.
3. Digital scoring tools for making and recording judgements.

Deciding what form each of these components would take started with an investigation of the nature of the performance to be assessed, how it was currently assessed (if at all), and any perceived deficiencies in the current assessment. Then, appropriate assessment tasks were devised and consideration of how digital technologies could be used to support performance on these tasks, and how performances could be best represented in digital form.

Capturing Performance

A variety of digital technologies may be used to capture student performance. The aim was to represent a student's performance on an assessment task by creating digital files that can be made available through online systems. This involved using a variety of cameras (e.g. SLR and video), microphones, digital scanners, USB Flash drives, applications software (e.g. documents, slideshows, spreadsheets, HTML editors), multimedia database systems, online portfolio and testing systems. It is likely that other methods of digital capture could be used and will become increasingly available.

Online Repositories

Student performance on assessment tasks needs to be judged by teachers or other experts; whether for the purpose of feedback and/or allocation of marks and grades. This means that assessors need to have access to the representations of student performance. If those representations are in digital forms, then using online repository systems to deliver them to assessors is likely to be the most cost-effective. This may be achieved through the simple storage of digital files in folders on computer servers that allow assessors to logon. However, it is more likely that online portfolio (e.g. MAPS) or exam

management (e.g. Willock) systems will be used. Issues that need to be considered include whether limitations and requirements need to be set for file formats and sizes, and whether any editing of files needs to be done before making them available to assessors (e.g. removing student identification).

Digital Scoring Tools

Assessing student performance requires assessors to be able access the representations of that performance, and a mechanism for recording their judgements, that is, a method of scoring and/or providing feedback. This can be achieved using digital scoring tools connected with the online repositories and a database for the recording of judgements. These systems typically allow the viewing of the digital representations and judgement criteria and recording of judgements and/or scores. Assessors can be located anywhere provided they have access to the Internet, and the recording of judgements allows a full analysis of them, including scores.

Most educators are familiar with forms of scoring that are analytical, where judgements are made against a number of stated criteria, often presented as a rubric. However, there are other methods including a holistic method of judgement, sometimes called pairwise comparisons, which were tried in these projects. Online database systems were used to implement both analytical and pairwise comparisons methods of scoring, the former using a custom *Filemaker Pro* system, and the latter using the *Adaptive Comparative Judgements System* (ACJS) as part of the *MAPS* online portfolio system.

The Examples

In the projects, many digital forms of assessment were devised for the various courses. In this section, only those from the courses specifically related to STEM are discussed, that is, from the Engineering Studies and Applied Information Technology (AIT) courses.

Engineering Studies Exam

The Engineering Studies course curriculum included a "focus on design through creative, practical and relevant opportunities to investigate, research and present information, design and make products, and undertake project development" (School Curriculum and Standards Authority 2015b). The intention was that learning activities would provide opportunities for students to "apply engineering processes, understand underpinning scientific and mathematical principles, develop engineering technology skills, and to understand the interrelationships between engineering projects and society". Three types of assessment are stated for the course: Design (30 %), Production (40 %) and Examination (30 %). That is, students "investigate needs, opportunities and problems that are defined in a design brief" (Design) and "manufacture and/or assemble their engineered product" (Production). When it comes to the external assessment, the assessment largely required students to write what they can remember of a body of content. Consequently, the external assessment was not only misaligned with the intended curriculum, but also with societal requirements.

In developing an appropriate assessment task, it was decided to start with a problem that lent itself to a solution that was design driven, and that could include a prototype production. For example, one of the problems that was used, asked students to design a system to produce drinking water from seawater only using specified materials, and only energy from the sun. Typically a time limit of around three hours was set within which students were guided through a design process that included using provided information, creating drawings and text to explain design ideas, getting feedback from others, creating a physical prototype and responding to questions about design and evaluation.

This approach to assessment was similar to that used in the British eScape project, and therefore, we first looked at using the digital technology support used in that project (Kimbell 2012). It used mobile devices to manage the assessment, collect evidence at each stage of the process including photographs, video, audio, drawing and text, and uploading these to an online e-portfolio system called *MAPS*. However, initially, the system was not easily customised so we developed our own using the *Filemaker Pro* database system. Eventually, the system used in eScape was commercialised as *LiveAssess* so we used it to manage all aspects of the assessment that eventually allowed the use of many types of digital devices and many types of control from local to remote.

AIT Assessment Tasks

The AIT course was designed for students to spend the majority of their time in class using digital technologies to develop information solutions. That is, it was intended to be a very practical course with about 50 % of the weighting of assessment to be on production. However, the external examination consisted only of multiple-choice, short answer and extended answer questions on paper with the resulting score being used to moderate the school score. This negated the balance of assessment between practice and theory, and did not reflect the intention of a practical course (School Curriculum and Standards Authority 2015a).

In developing an appropriate assessment task, it was decided to focus on problem-based designed production information solutions, somewhat similar to that for Engineering Studies, with a prototype created using a range of provided software. It was decided to trial two forms of assessment, a digital reflective process portfolio and a production exam. The former was to be longer term (e.g. 4 weeks) allowing the development of larger more sophisticated information solutions, while the latter was to be two to three hours allowing only limited development. Specifically, the digital reflective process portfolio was to be completed over a number of weeks during class time, be uploaded to an online portfolio, and include:

1. A digital product designed as a prototype of an information solution.
2. The design process document for that digital product.
3. Two other digital artefacts that illustrate skills in other areas.

The production exam was to be completed in one class session under exam conditions using a computer workstation, design sheets and USB flash drive with digital material to use to construct a prototype solution (e.g. graphs, logo, brochure, poster or interactive display). The resulting files would be submitted online and/or on USB flash drive. An example of a design problem used for this exam was to design and create an online help facility for primary students to use the *SmartRider* public transport card. Students were provided with a limited set of digital multi-media materials to use and were guided through a structured design and production process.

Implementation of Digital Forms of Assessment

The research projects demonstrated that a number of digital forms of assessment could be readily implemented in typical Western Australian secondary schools, using the schools' own computers, with offline backup storage, and a school IT support technician on-call to overcome rare obstacles. It was found that in general, almost all students preferred digital forms of assessment to paper-based, even where they perceived that their levels of ICT skill were relatively low. However, they needed to have confidence in the reliability of the hardware and have had some experience with using the software and the form of assessment. Fortunately, the vast majority of students were able to quickly learn to use the software required in the assessments (e.g. for typing, drawing diagrams, recording audio and video). Further, almost all teachers in the AIT and Engineering Studies courses were happy to use digital forms of assessment provided that the benefits were clear, implementation was simple, and the software was accessible and easy to use.

Increasingly, the education systems of developed countries are implementing various digital forms of assessment. For example, currently, it has been suggested that for elementary and middle schools in the USA, the "majority of state-mandated end-of-year summative tests students will take will be via computer administration and not via paper-and-pencil format" (EdTech Strategies 2015). Currently, 11 states of the USA deliver all mandatory testing using online technologies. This trend is likely to encourage teachers to make more use of ICT to support STEM learning and this in turn may lead to more learning activities that are problem-based and integrated across the curriculum. It will certainly remove one of the current obstacles of paper-based assessment.

Conclusion

It is clear that increasingly the Australian economy and society needs citizens with STEM knowledge and skills (Ritz and Fan 2015), but that currently for most children, this is not adequately provided through the school systems (Office of the Chief Scientist 2014). While most students may study some science, technology, engineering and mathematics courses, it is unlikely that they do this in the integrated manner that is needed for application to real problems, that is, STEM learning (Myers and Berkowicz 2015a; Blackley and Howell 2015). Further, the manner in which many of these courses are presented to students is perceived by many of them as boring (Sanders 2012). How can this STEM boredom be reduced? The use of ICT to support learning activities can be part of the solution.

There are many ways teachers can employ ICT with students to support enhanced learning environments that includes quality learning activities, drawing on knowledge and skills across STEM disciplines, and aimed at improving conceptual understanding. There is substantial evidence that ICT can be used purposefully to support better implementation of those learning activities and environments (Stoilescu 2015). Teachers need to be supported to implement this ICT support with school leaders removing barriers to implementation. In particular, it is important that methods of assessment do not become a barrier and in fact that we assess what we want students to know how to do, particularly in the application of STEM skills and knowledge. This is a time of great opportunity to improve STEM learning for all children, but it is a challenge for Australian teachers and school leaders to grasp and realise.

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