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Comparison of Technology Use Between Biology and Physics Teachers in a 1:1 Laptop Environment

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Abstract

Using a mixed-methods approach the authors compared the associated practices of senior physics teachers (n = 7) and students (n = 53) in a 1:1 laptop environment with those of senior biology teachers (n = 10) and students (n = 125) also in a 1:1 laptop environment, in seven high schools in Sydney, NSW, Australia. They found that the physics teachers and students reported more use of their laptops than did their biology counterparts, particularly in regard to higher order, engaging activities such as simulations. This disparity is consistent with the differences between the prescribed NSW physics and biology curriculum documents. The physics curriculum specifies that students should engage with various technologies (especially simulations) frequently within the course content, while the biology curriculum makes only generic statements within the course outline. Due to the curriculum mandate, physics teachers seemed to be capitalizing on the opportunities afforded by the 1:1 laptop environment, whereas the biology teachers had less of a mandate and, consequently, incorporated less technology in their teaching.

A recent study found that senior students in a 1:1 laptop environment performed significantly better in external standardized examinations than did those without laptops in both biology and physics (Crook, Sharma, & Wilson, 2015). The effect sizes (Cohen's *d*) of being schooled with 1:1 laptops in these subjects were 0.26 and 0.38, respectively. The substantially larger effect size in physics was an interesting result. Consequently, we determined to investigate why students in physics appear to be better able to leverage the opportunities afforded by a 1:1 laptop environment compared to students in biology. Additional questions included the following:

- What were the differences in the practices of the teachers and students in physics compared to those in biology?
- Are there any differences in the mandatory and recommended uses of technology in the respective curriculum documents?
- Can this difference be related to technology, pedagogy, and content knowledge (TPACK)?
- What implications would these answers have on the preservice training and professional development of science teachers?

Background

From 2008-2012, the Australian Government implemented a $2.1 billion 1:1 laptop initiative known as the Digital Education Revolution (DER) across the whole country (Digital Education Advisory Group, 2013). The objective of the DER was to create a 1:1 computer-to-student ratio for grades 9-12 in all secondary schools within 5 years. In recent years a variety of research has been undertaken to review the DER (Crook & Sharma, 2013; Crook et al., 2015; Crook, Sharma, Wilson, & Muller, 2013; Dandolopartners, 2013; Howard & Mozejko, 2013). However, of the studies we found, none thus far have examined the role of prescribed curriculum content in the uptake and integration of technology in class, nor have any incorporated the TPACK framework.

Across the state of New South Wales (NSW), Australia, all senior students (Grades 11 and 12) within particular subjects follow the same curriculum documents created and prescribed by the Board of Studies NSW (Board of Studies NSW, 2009b). These curriculum documents or syllabuses specify detailed content that should be taught, often recommending *how* the content should be taught and specifying what students should *learn* and*do*. At the end of Grade 12 all students sit for the statewide Higher School Certificate (HSC) external standardized examinations, which ultimately determine a student's overall score and eligibility for admission into various university degree programs (Universities Admissions Centre, 2009). The curriculum documents specify the precise content that is examined in these high-stakes examinations. Furthermore, the Board of Studies NSW provides standards packages to illustrate performance in different syllabus areas in relations to standards-based assessment (Board of Studies NSW, 2006).

This study focuses on seven high schools from the Catholic Education Office (CEO) Sydney, Southern Region, that were issued laptops for every Grade 9 student in 2008, as part of the first roll out of the DER. Consequently, this first cohort of students with 1:1 laptops graduated from Grade 12 in 2011 having sat for the external, standardized NSW HSC examinations. This study examines the 2011 Grade 12 physics and biology students and teachers from these seven schools to explore their integration of technology with the 1:1 laptops and uncover any notable differences.

A particular focus of our previous studies has been on the impact of the 1:1 laptop environment on teaching and learning in the sciences. These studies have concentrated on the practices of teachers and students and comparisons between them, the activities in which they engage in terms of higher and lower order thinking, and multiple regression analyses to determine whether being schooled in a 1:1 laptop environment offered any advantage in external standardized examinations (Crook & Sharma, 2013; Crook et al., 2015; Crook et al., 2013). Having determined *what* happens to student attainment in a 1:1 laptop environment in the previous studies, this study determined to find out *why*.

Review of the Literature

Given the context of this study, we reviewed the literature around technology in teaching, particularly science teaching; 1:1 laptops in teaching, particularly science teaching; approaches to technology integration in science curricula; and TPACK.

Technology in Science Teaching

Technology has long been a part of science instruction, with science teachers often being considered innovators and leaders in the use of technology over many decades (McCrory, 2006). In more recent times the technologies used in science teaching have been specifically digital technologies, be they online resources, software, or physical computers and devices.

Some of the latest practices and research in teaching science have been around the use of tablets (such as iPads®; Miller, Krockover, & Doughty, 2013; Wilson, Goodman, Bradbury, & Gross, 2013). The use of technology in the classroom or laboratory has been shown to increase motivation and learning and offer new opportunities through various simulations (Khan, 2010; Quellmalz, Timms, Silberglitt, & Buckley, 2012; Wieman, Adams, & Perkins, 2008), and science software (Baggott la Velle, Wishart, McFarlane, Brawn, & John, 2007; Zheng, Warschauer, Hwang, & Collins, 2014). Similarly, students who are confident with basic information and communications technology (ICT) tasks have been found to have higher scientific literacy (Luu & Freeman, 2011).

Of course, no one is suggesting that science teaching should be conducted through technology alone. The best learning outcomes are obtained through a combination of real and virtual experiences (Olympiou & Zacharia, 2012), and evidence-based effective teaching practices should be followed (Bryan, 2006). New tools are also evolving that might change the landscape of science teaching, such as those that can automatically score students work, offering personalized guidance in science inquiry (Linn et al., 2014) and effecting instructional quality through their mediation of research-proven practices and classroom instruction (Weston & Bain, 2014).

To understand the role of technology in science attainment, researchers have examined ICT access and use in relation to international attainments in scientific literacy, as assessed by PISA (e Silva, 2014; Luu & Freeman, 2011). After controlling for demographic characteristics, use of technology was found to have a modest but consistently positive impact upon scientific literacy. However, Luu and Freeman (2011) pointed out that the ways in which students use computers in schools may have a stronger effect than how often computers are accessed, and e Silva (2014) said, “What we loose [sic] in these huge statistical studies is the detail. We need now to know what works and what does not work in each situation” (p. 6).

However, the detail in implementation of innovative technology tools by science teachers is very much dependent on their personal beliefs, motivations, and contexts regarding technology and science teaching as a whole (Kim, Hannafin, & Bryan, 2007; Stylianidou, Boohan, & Ogborn, 2005). In technologically enhanced environments, student-centered approaches have been demonstrated to be more effective than teacher-guided approaches (Hsu, 2008) and to facilitate significantly higher emotional engagement in the students (Wu & Huang, 2007).

A variety of literature exists specifically around the use of 1:1 laptops in science teaching. Within a middle school context, Yerrick and Johnson (2009) found that by inserting laptops and science technology tools in the classrooms of motivated science teachers, students found their teachers to be more effective, and the teachers themselves also reported renewed vigor in their teaching with improved scores on students' attainment.

In another middle school context, Berry and Wintle (2009) noted that students learning science with 1:1 laptops experienced increased engagement, comprehension, and retention of learning. Even though learning required more effort than traditional methods, it was more fun.

Zucker and Hug (2007, 2008) provided examples of ways 1:1 laptops can be used effectively to teach and learn high school physics at the Denver School of Science and Technology. They found that the physics teachers there made use of the many affordances of the digital technology, providing their students with high-quality tools to explore scientific concepts. Again in a middle school context, a quantitative analysis by Dunleavy and Heinecke (2008) showed significant positive effects of 1:1 laptop instruction on student achievement in science.

Along with our previous work, this study will provide some much-needed research documenting and analyzing the use of 1:1 laptops in senior high school science beyond middle school. Our aim is to identify practices that are reported in classrooms where 1:1 laptop use is positively associated with higher attainment.

Technology in Science Curricula

An important part of this study is the embedding (or lack thereof) of technology in the recommended and mandatory activities in science curricula. Hennessy et al. (2007) highlighted that existing pedagogical approaches and thinking are limited by "the systemic subject culture of secondary science which imposes tight curriculum time constraints" (p. 147). In a similar contemporary vein, teachers have expressed concerns about the limited connections between curricula and game-based learning (Sadler, Romine, Stuart, & Merle-Johnson, 2013). Others have noted that the success of integrating new technology into education varies from curriculum to curriculum (Becta, 2003; Bingimlas, 2009).

Braund and Reiss (2006) argued that to create a more authentic science curriculum requires learning both in and out of school, particularly capitalizing on virtual worlds through information technologies. In a recent study, 48 preservice science teachers were asked, "What does technology integration mean to you?" (Green, Chassereau, Kennedy, & Schriver, 2013, p. 397). The common misconception that emerged was that many teachers see technology integration as a tool in itself but do not see how that tool can enhance the curriculum; that is, some teachers use technology for the sake of using technology rather than understanding how it can improve teaching and learning.

The Board of Studies NSW prescribes syllabuses to be followed by all students within every subject. The syllabuses not only recommend and mandate activities that teachers should employ, including the integration of technology, but also specify what students should learn and, oftentimes, how they should learn it (Board of Studies NSW, 2009b). More recently, in preparation for the new Australian Curriculum, the national Australian Curriculum, Assessment and Reporting Authority (ACARA, 2011b) has prepared curriculum documents for K-10 specifying the integration of technology in every subject through the *ICT General Capability*. In NSW, the Board of Studies has adapted the ACARA material to create syllabuses for every subject, K-10, again including the *ICT General Capability* (Board of Studies NSW, 2012). However, in the interim and at the time of this study for Grades 11 and 12, in NSW students will still follow the Board of Studies NSW HSC syllabuses (Board of Studies NSW, 2009b).

Within this context of specific and detailed curricula, our study examines classroom practice with 1:1 laptops. To analyze the complexities involved we drew on the TPACK theoretical framework in order to examine the different aspects of classroom practice reported by students and teachers.

TPACK

Building on Shulman's (1986, 1987) construct of pedagogical content knowledge (PCK), Mishra and Koehler described technological knowledge as a domain of a more specific *technological* pedagogical content knowledge (Koehler & Mishra, 2009; Mishra & Koehler, 2006), which later became referred to as technology, pedagogy, and content knowledge, or TPACK (Thompson & Mishra, 2007). TPACK is a conceptual framework to describe the knowledge base teachers need to teach effectively with technology (see Figure 1).

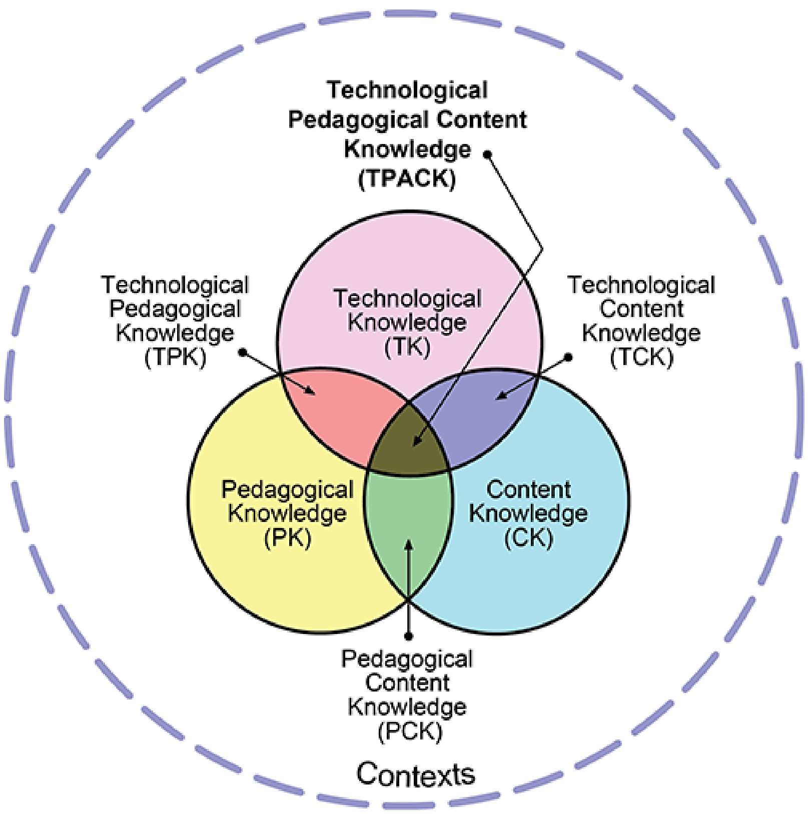


Figure 1. *Technological pedagogical content knowledge (TPACK). Reproduced by permission of the publisher, © 2012 by tpack.org*

Prior to Mishra and Koehler describing TPCK/TPACK, Niess (2005) described an adaptation of PCK she called "technology-enhanced PCK" (and also "technological pedagogical content knowledge"). In her study, Niess examined a teacher preparation program designed to empower science and mathematics teachers to integrate technology. Of the 22 teachers studied, 17 were science teachers of various disciplines. The study "uncovered an important consideration in the development of TPCK—the interaction of the content of science/mathematics and the content of the specific technology…[however,] only some of the students recognized the interplay of technology and science" (p. 520).

In a study of 4 in-service secondary science teachers, researchers found that "contextual constraints such as availability of technology tools and characteristics of student population had large impacts on the teachers' development of TPACK" (Guzey & Roehrig, 2009, p. 40). In another study by the same authors looking at three beginning science teachers, they found that "intrinsic motivation in conjunction with beliefs and knowledge drives teachers to use educational technology tools in their teaching…[and] that reflection is critical for sustained technology use" (Guzey & Roehrig, 2012, p. 178).

In a case study of three preservice physics teachers, Srisawasdi (2012) recorded their respective transformation over time in PCK, technological content knowledge (TCK), technological pedagogical knowledge (TPK), and ultimately, their increased competence in TPACK. Srisawasdi was also noted that "competency of TPACK could directly impact on students' conceptual learning in physics" (p. 3243). In a study of 4 physics student teachers Alev and Yiğit (2011) found that they began with limited technological knowledge and insufficient pedagogical knowledge. However, through a process of reflection they developed transformative uses of technology through new pedagogical practices, that is, TPACK.

TPACK has also been used in the context of biology preservice teachers around using computer technology to support reforms-based science instruction (Schnittka & Bell, 2009). Recently, a study examined the development of TPACK in mathematics and science preservice special education teachers (Tournaki & Lyublinskaya, 2014). Focusing on three domains of knowledge related specifically to integrating instructional technology (i.e., TPK, TCK, and TPACK), they found significant gains with large effect sizes in teachers' knowledge in these domains due to the embedding of TPACK in their preservice course. A byproduct was a significant gain but moderate effect size in PCK.

The idea of TPACK is constantly evolving from its original PCK (Shulman, 1986) roots. Of potential use for science teachers (although yet to gain traction), Jimoyiannis (2010) took TPACK and an authentic learning approach in science to create technological pedagogical and science knowledge (TPASK); a new model for science teachers professional development, essentially TPACK in science education (Voogt, Fisser, Pareja Roblin, Tondeur, & van Braak, 2013). It remains to be seen if TPASK is adopted and is of any benefit within science education.

Using TPACK as a theoretical framework, Khan (2010) examined how simulations were employed across 11 science topics in the science curriculum and enhanced conceptual understanding. Khan found that "special insights into an experienced science teacher's TPACK can reveal key heuristics and instructional patterns on effective classroom-based methods for teaching with technology" (p. 229). Using TPACK as a framework to investigate technology-enhanced scientific inquiry instruction in 27 preservice teachers, it was found that "integrating technologies such as digital images, simulations, spreadsheets, and probeware can help teachers engage their students in observational, correlational, and experimental inquiry investigations" (Maeng, Mulvey, Smetana, & Bell, 2013, p. 855).

TPACK has also been used recently as a framework in a 1:1 laptop environment, albeit in a social studies context. A recent study found that since "access to classroom technologies continues to become more ubiquitous, more novice teachers are going to be asked to teach in technology-rich environments, so it is imperative that they learn to think from a TPCK standpoint before entering the field as professionals" (Walker Beeson, Journell, & Ayers, 2014, p. 10).

Harris, Mishra, and Koehler (2009) highlighted the problems with the general approaches that dominate current and past technology integration efforts in teaching. They stated that "these approaches tend to initiate and organize their efforts according to the educational technologies being used, rather than students' learning needs relative to curriculum-based content standards, even when their titles and descriptions address technology integration directly" (p. 395). The solution they purport is TPACK: "a form of professional knowledge that technologically and pedagogically adept, curriculum-oriented teachers use when they teach" (p. 401). This work supports the use of TPACK as an organizing framework to assure that technology, pedagogy and content are all included in the researcher's lens when exploring technology integration phenomena.

There are no references to TPACK within the Board of Studies NSW physics and biology syllabus documents examined in this study. This was to be expected since they were first written in 2002 and predate references to TPACK in the literature. However, with the advent of the new Australian Curriculum, there is a brief reference to TPCK by ACARA (2014), where it is stated, "Professional learning and resources that highlight suitable pedagogies, for example technological pedagogical content knowledge (TPCK) would be desirable" (p. 1). However, this occurrence is only within the curriculum area of *Digital Technologies* and not within the cross-curricula *ICT General Capability*. At the time of writing no references to TPCK/TPACK appear at all in the Board of Studies NSW materials for sciences.

Purpose of the Study

In view of the extant literature, including our previous study which found that the effect size of 1:1 laptops on student attainment was greater in physics than biology, this study examined the technology uses of teachers and students in senior physics and biology in a 1:1 laptop environment and compared between these subject disciplines to provide some explanation for the greater effect size in physics. To inform this comparison we needed to consider the respective curriculum documents in terms of the integration of technology and present these findings within the framework of TPACK.

Research Questions

1. Given that the effect size of the impact of 1:1 laptops on student attainment in NSW HSC physics was previously found to be significantly larger than that in biology, what are the differences in the teacher and student use of the laptops between the two subject disciplines?
2. Are there any differences in the opinions of the physics and biology teachers and students regarding the value and impact of the 1:1 laptops on their respective teaching and learning?
3. Are there any differences in the syllabus requirements for the integration of technology between the prescribed NSW HSC physics and biology curriculum documents? If so, how do these differences relate to differences in use identified in Questions 1 and 2?
4. Can any differences found in Questions 1, 2, and 3 be interpreted in terms of the TPACK framework?

Methods

Within this study we used a mixed-method approach to address the research questions sequentially:

- A quantitative analysis of exit questionnaires for teachers and students to explore their self-reported integration of technology via 1:1 laptops in the teaching and learning of physics and/or biology.
- A qualitative analysis of written comments from teachers and students from exit questionnaires regarding their perceived value and impact of 1:1 laptops on the teaching and learning of their subject.
- A curriculum document analysis to identify mandatory and recommended inclusions for the integration of technology in the respective statewide prescribed physics and biology curriculum documents.
- A mapping and interpretation exercise to frame any inclusions of the integration of technology in terms of TPACK found in teachers' and students' practices, in teachers' and students' perceptions, and in the curricula.

In 2011, in the 2 months prior to Grade 12 students sitting their statewide HSC examinations, we issued questionnaires to every Grade 12 student in physics (n = 113) and biology (n = 246), and every Grade 12 teacher in physics (n = 8) and biology (n = 13) from the seven schools in the CEO Sydney, Southern Region, with 1:1 laptops. The questionnaires were administered via Google Doc Forms (with the links sent via email) for ease, efficiency, security (then 128-bit encryption), anonymity, and the minimization of errors due to transcription. The respective response rates to the questionnaires were 47% for physics students, 51% for biology students, 88% for physics teachers, and 77% for biology teachers. These response rates far exceeded the average response rate for email-administered online surveys of 24% (Kaplowitz, Hadlock, & Levine, 2004), but nevertheless, constrained the representativeness of the sample.

Sample

The Grade 12 physics and biology teachers and students were from seven comprehensive high schools in CEO Sydney of varying socioeconomic, gender, and grade profiles (see Table 1). However, these schools all had a similar technological profile, with every student having been provided with a laptop due to the DER. Similarly, each school provided all teachers with their own laptops. Table 1 presents the profiles of the seven schools and the two respondent groups for students and teachers in physics and biology.

More students studied biology (n = 125) compared to physics (n = 53). Contributing to this ratio, in general, many more girls studied biology (58%) than studied physics (30%; Baram-Tsabari & Yarden, 2008), which is often because it is seen as a pathway to careers in healthcare (Fullarton, Walker, Ainley, & Hillman, 2003).

Only 9 students studied both physics and biology. However, these students were excluded because their experiences with technology in one subject likely influenced their experiences in the other. Hence, they were not considered in the physics or biology samples in this study. They were not considered separately as a whole group within this study due to the small sample size.

Table 1
Profiles of Schools, Students, and Teachers

Group	Profile
Schools	There were 7 schools studied: 2 boys', 1 girls' and 4 coeducational schools; 5 were 7-12 schools and 2 were 11-12 senior schools; the schools ranged in socioeconomic status from 980 to 1088[a]; the total number of respondent physics students ranged from 4 to 12 per school; the total number of respondent biology students ranged from 2 to 42 per school; the schools' average score for prior attainment ranged from 77.9 to 84.8[b]. Every school had 1 physics class and teacher, apart from one school with 2 classes and 2 teachers; and 1-3 biology classes with 1-3 biology teachers.
Physics students	There were *n* = 53 respondent physics students from across all 7 of the schools studied. The range of prior attainment for the physics students was 77 to 96. 30% of the physics students were girls.
Biology students	There were *n* = 125 respondent biology students from across all 7 of the schools studied. The range of prior attainment for the biology students was 58 to 96. 58% of the biology students were girls.
Physics teachers	There were *n* = 7 respondent physics teachers from across all 7 of the schools studied. 43% (3/7) of physics teachers were female. Each teacher taught one physics class.
Biology teachers	There were *n* = 10 respondent biology teachers from across all 7 of the schools studied. 60% (6/10) biology teachers were female. Each teacher taught one biology class.

[a] The school socioeconomic status was obtained from the Index of Community Socio-Educational Advantage 2011, as presented on the MySchool website.
[b] In Grade 10 2009 every student sat for the statewide School Certificate Science standardized examination, with a score out of 100. This exam is used as a measure of prior attainment, demonstrating a high degree of correlation with later attainment in the senior sciences (Crook et al., 2015).

Regarding prior attainment, the range of School Certificate science scores for biology students (58-96) was much greater than that for physics students (77-96), with biology exhibiting a far longer tail. The mean Grade 10 school certificate score for biology was 82.6 (*SD* = 6.9) and for physics was 88.1 (*SD* = 5.1). With physics and biology students represented from every school, the sociodemographic variability across the schools was reflected in the respective physics and biology student samples.

Given the greater numbers of biology students, there was necessarily a greater number of biology teachers. As with the student profiles, there was a greater percentage of female biology teachers (60%) than female physics teachers (43%).

Procedure and Instruments

Use of laptops. The respective teacher and student questionnaires asked the same three type-of-use questions. From a tick-a-box list that included the options word processing, spreadsheets, presentation software, simulations, science software, electronic textbook, wikis, blogs, Internet research, learning management system (LMS), video editing, podcasting, databases, email, and datalogging, every teacher and student was asked the following:

- From the list please select *ALL* activities/applications that you have been asked to use as part of your physics/biology studies?
- From the list please select *up to 3* activities/applications you *MOST ENJOY* doing as part of your physics/biology studies?
- From the list please select the *up to 3* activities/applications you use *MOST OFTEN* as part of your physics/biology studies?

The results for each population group were then tallied and compared using *explosion* charts (see Results).

Qualitative analysis of comments. Within the questionnaire, teachers and students were each asked to write a comment regarding their perceptions of the value of studying their respective science with a 1:1 laptop. These written responses were analyzed using inductive qualitative content analysis (Elo & Kyngäs, 2008) using NVivo.

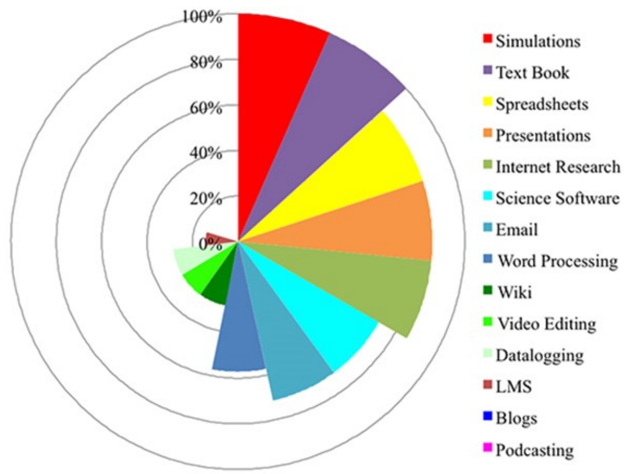
Analysis of curricula. The curriculum documents followed by the physics and biology students were the respective Board of Studies NSW HSC syllabuses (2009a, 2009c), both originally written in 2002. The structures of the two curricula were examined with regard to the role of technology in the syllabuses. Similarly, both curriculum documents were analyzed by inspection for inclusions regarding the integration of technology. The terms that were searched for were *technology/ies* (not including biotechnology), *computer* (not including the actual physics of computers), *digital* (not including the actual physics of digital), *word processing, spreadsheets, presentation software, simulations, science software, electronic textbook, wikis, blogs, Internet research, learning management system, video editing, podcasting, databases, email and datalogging*. By these means the two curricula were compared and contrasted.

Results

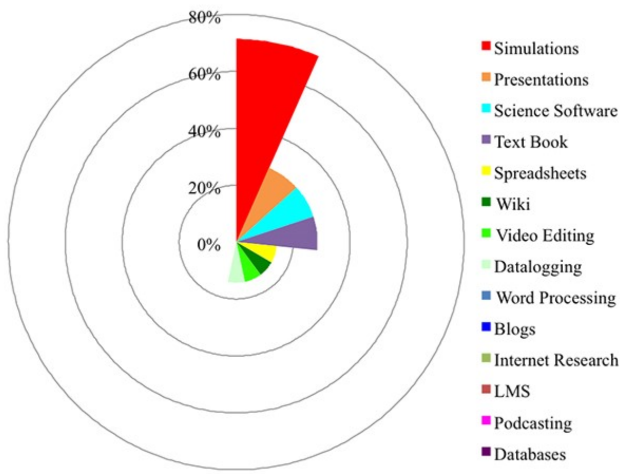
The results are sequenced to present the teacher responses, followed by the student responses and finally the curriculum document analysis.

Teachers

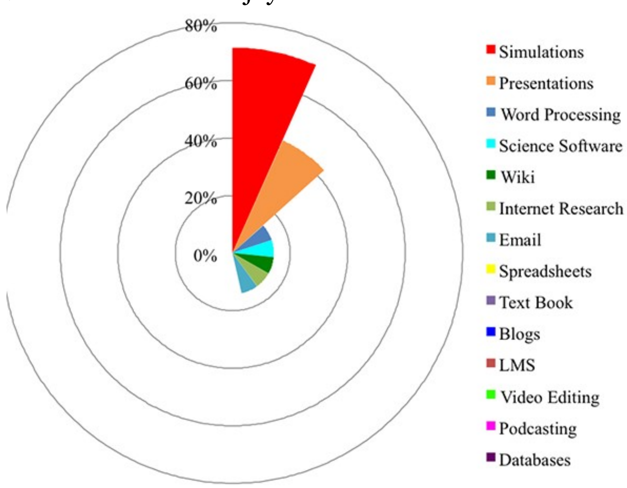
The data gathered from the three questions on type of use of the 1:1 laptops were processed to create explosion charts to draw comparisons. Each explosion chart contains one sector per activity, with the radius representing the magnitude (i.e., percentage of respondents), as compared to a pie chart where the magnitude is represented by the angle. For the ease of the reader every activity has its own color; for example, simulations are red. The key is included with every chart, as it also presents the hierarchy in each case. Within every triplet of charts, the first chart always has a scale up to 100%, whereas the second and third charts only scale up to 80% to aid the reader, since no values exceeded 80% within the second and third charts.



a. All activities.

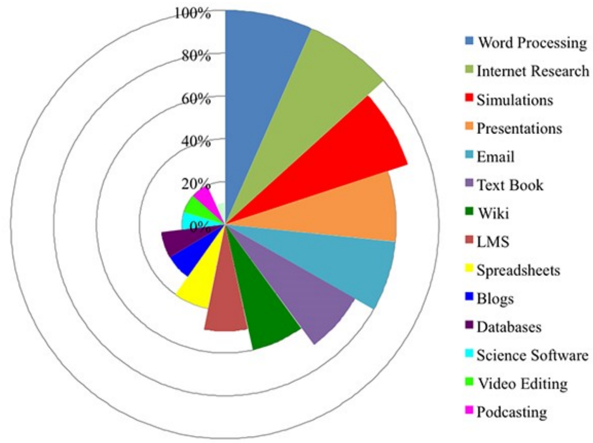


b. Activities most enjoyed.

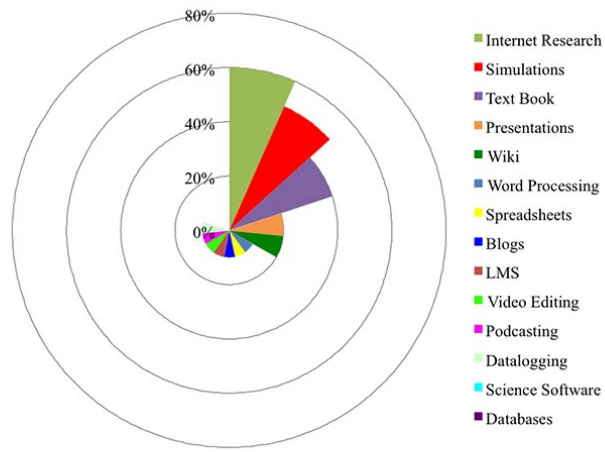


c. Activities most often.

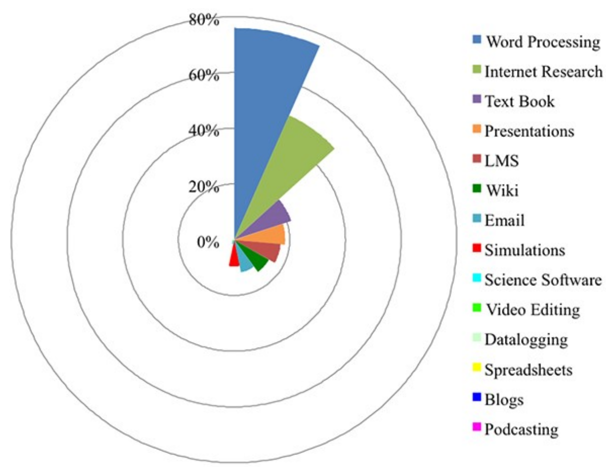
Figure 2. *Laptop activities engaged in by physics teachers.*



a. All activities.



b. Activities most enjoyed.



c. Activities often.

Figure 3. *Laptop activities engaged in by biology teachers.*

Laptop use. A comparison of Figures 2a and 3a highlights the differences between all of the activities and applications that physics teachers reported using on their laptops, compared to those reported by their biology colleagues. One hundred percent of the physics teachers reported using simulations and electronic textbooks (100%); spreadsheets, presentation software, and Internet research were each individually reported by 86% of the physics teachers. On the other hand, the biology teachers' top three most-reported applications were word processing (100%), Internet research (100%) and simulations (90%).

Only 57% of physics teachers reported using their laptops for word processing compared to 100% of biology teachers, whereas 86% of physics teachers reported using spreadsheets compared to only 40% of biology teachers, and 71% of physics teachers reported using science software compared to only 20% of biology teachers. Spreadsheets and science software, engaged in by a far greater percentage of physics teachers, would be considered capable of facilitating higher order activities, whereas word processing—engaged in by a far greater percentage of biology teachers—would be considered to enable lower order activities. (The terms*higher* and *lower order activities* pertain to using higher and lower order thinking skills, as defined in Bloom's Digital Taxonomy, Churches, 2009; Crook & Sharma, 2013).

Enjoyment. Figures 2b and 3b enable comparisons between the activities physics and biology teachers most enjoyed: The physics teachers most commonly reported enjoying simulations (71%); presentation software, science software, and electronic textbooks were each individually reported by 29% of physics teachers. The biology teachers reported most enjoying Internet research (60%), simulations (50%) and electronic textbooks (40%).

No physics teachers reported enjoying Internet research, while 60% of biology teachers did. However, 29% of physics teachers reported enjoying science software, compared to 0% of biology teachers; and 71% of physics teachers enjoyed simulations, compared to 50% of biology teachers.

Again, science software and simulations can enable higher order activities thinking, whereas Internet research would be considered as enabling lower order activities (Churches, 2009; Crook & Sharma, 2013).

Frequency of use. Figures 2c and 3c show which 1:1 laptop activities physics and biology teachers reported doing most often. Most often, physics teachers reported using simulations (71%), and presentation software (43%). In equal third place were word processing, science software, wikis, Internet research, and email (14%). Biology teachers reported most often using simulations (50%), Internet research (50%), and word processing (40%). The most sizeable differences between the two subject areas were Internet research (physics 14%, biology 50%), word processing (physics 14%, biology 40%), and presentation software (physics 43%, biology 20%).

Emergent trends observed included the following:

- Physics teachers reported use of simulations (discussed later) with the greatest frequency and also as the most enjoyable activity and the activity most often engaged in.

- Biology teachers reported Internet research with the first or second highest frequency for all three questions.
- When reporting on the activities most enjoyed and those engaged in most often, the physics teachers, as a whole, opted not to report about half of the activities each time. However, this is probably due to the smaller number of physics teachers (n = 7).

Students

Figures 4 and 5 present the reported data from the physics and biology students.

Laptop use. Figures 4a and 5a compare all of the activities physics and biology students engaged in within their respective subjects with their laptops. Of all of the activities, the three most reported by physics students were word processing (91%), Internet research (85%) and electronic textbooks (72%). For biology students the three most-reported activities were word processing (94%), Internet research (85%), and the LMS (63%). The starkest differences between the two subjects were in relation to simulations (physics 60%, biology 18%), spreadsheets (physics 40%, biology 16%), and science software (physics 32%, biology 11%). (Compare the frequencies for simulations to the 10% average found by the Organisation for Economic Co-operation and Development [OECD], 2011).

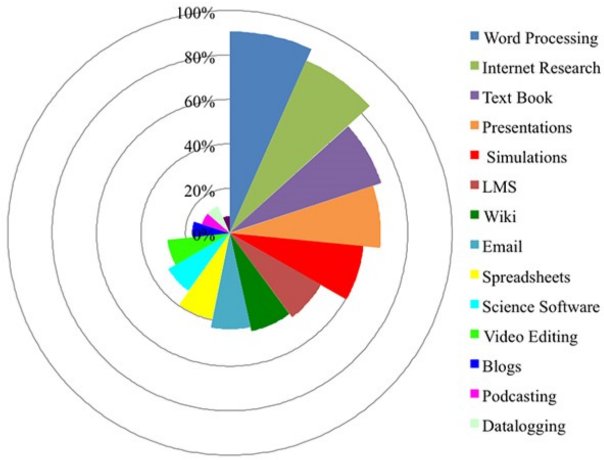
These results imply that a greater percentage of physics students engaged in higher order technology integration in their learning than did the biology students.

Comparing between biology teachers and students (Figures 3a and 5a), it would appear that, although 90% of biology teachers reported using simulations in their teaching, a degree of misalignment is apparent (as also identified in Crook et al., 2013). Only 18% of biology students reported the same experience (Crook & Sharma, 2013).

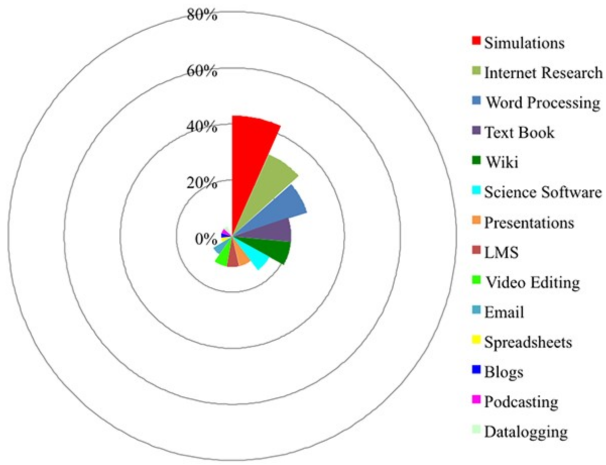
Enjoyment. In terms of what the students most enjoyed, the top three activities in physics were simulations (43%), Internet research (32%), and word processing (28%). In biology it was Internet research (54%), word processing (42%), and presentation software (25%). The largest differences were in relation to simulations (physics 43%, biology 18%), Internet research (physics 32%, biology 54%), and word processing (physics 28%, biology 42%).

These data show that a greater percentage of physics students enjoyed the higher order activity of simulations than did biology students, whereas many more biology students enjoyed the lower order activities of Internet research and word processing than did physics students.

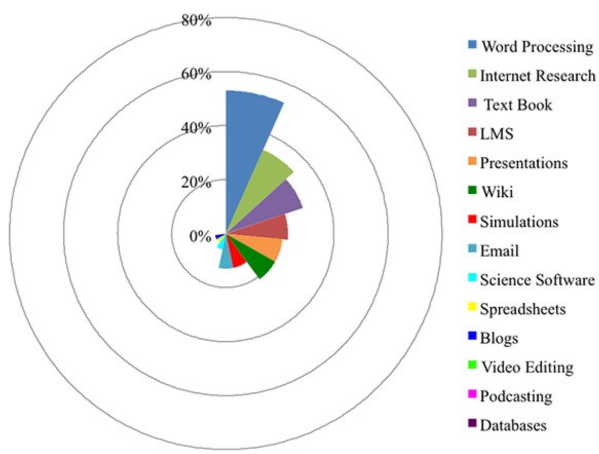
Frequency of use. An interesting overarching observation is what the students reported engaging in most often. Both physics and biology students reported most often engaging with word processing (physics 53%, biology 76%), Internet research (physics 34%, biology 49%), and electronic textbooks (physics 30%, biology 22%), in the same order. These are the same lower order activities, in the exact same hierarchy as reported by Grade 10 science students from the same schools in 2010 (Crook & Sharma, 2013). On a day-to-day basis, word processing, Internet research, and electronic textbooks would appear to be the lower order modus operandi for junior and senior science students.



a. All activities.

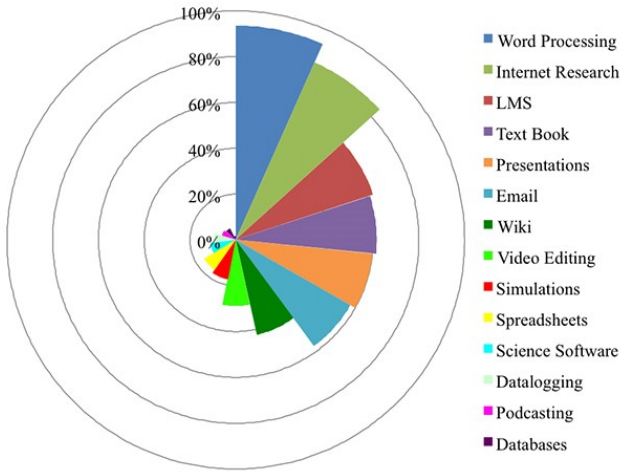


b. Activities enjoyed.

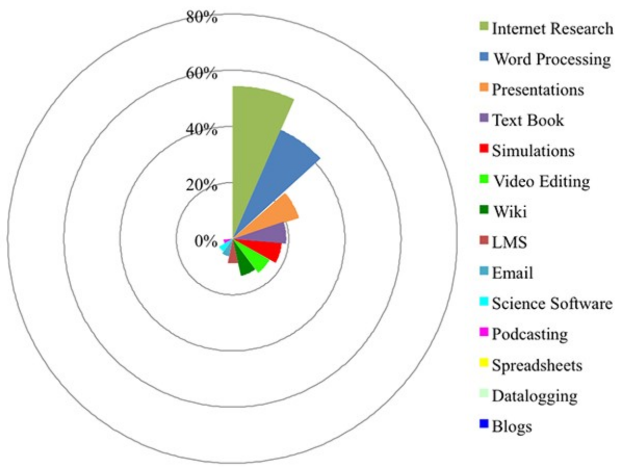


c. Activities often.

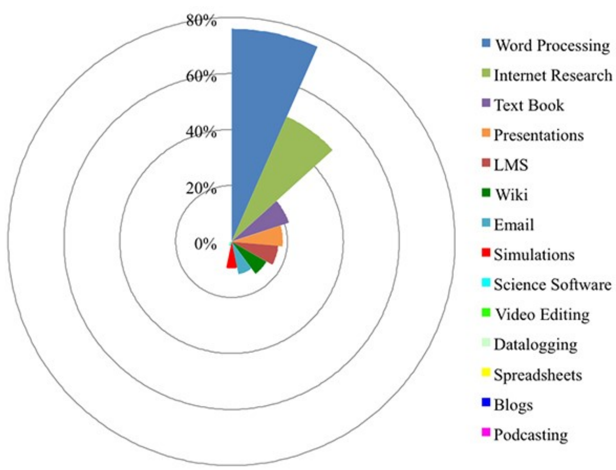
Figure 4. *Laptop activities engaged in by physics students.*



a. All activities.



b. Activities enjoyed.



c. Activities often.

Figure 5. *Laptop activities engaged in by biology students.*

Qualitative analysis of comments. Given the opportunity to write a comment within the questionnaire about using 1:1 laptops in their study of their science, the response rates among the actual respondents—physics teachers (2/7), biology teachers (3/10), physics students (11/53) and biology students (16/125)—were disappointing. Nevertheless, they were subject to inductive content analysis (Elo & Kyngäs, 2008).

In Table 2 the terms most commonly referred to by the students are ranked and tallied in the positive, neutral, and negative manners in which they were used. Regarding the physics students who added comments, most terms were most often used negatively ("-" scored highest most often), with only two terms, *students* and *way*, most often used neutrally.

Table 2
Terms in Student Comments

Hierarchy	Physics	+, 0, -	Biology	+, 0, -
1	students	2, 6, 3	use	5, 1, 9
2	use	2, 4, 5	students	0, 2, 7
3	school	0, 2, 7	distraction	0, 0, 8
4	teachers	2, 2, 4	learn	2, 0, 6
5	way	0, 4, 3	education	1, 0, 5
6	distraction	0, 1, 6	class	0, 1, 4
7	motivation	1, 0, 4	affected	0, 0, 4

With the biology students who contributed comments, all of the most common terms were most often used in a negative manner. Some typical comments included the following:

> Laptops are quite possibly the worst thing to ever happen to schooling. They are a major distraction and they pose no benefits. All teachers want students to do podcasts and other technologically advanced presentation mediums. All teachers think that students love doing all this stuff but quite frankly it is pointless and boring. Either way students are going to hate doing assignments regardless of their form. Teachers also try to make students make use of [LMS] information but it is just a hassle and students would rather hand outs [sic] this way they can study off them and highlight appropriate things. [Physics student]

> Sometimes the laptop is an extrerme [sic] distraction and if everything is going negative for the class atmosphere it is always a big temptaion [sic] to simply play games or do anything other than the work that is recquired [sic]. [Biology student]

It would appear from these limited comments that students believe the implementation of the 1:1 laptops to be detrimental to the study of senior physics and biology, although evidence indicates otherwise (Crook et al., 2015). Given the low response rate for comments, possibly only those students who had a complaint were the ones who commented. However, these comments should not be dismissed out of hand, since technology use can mold students' interest in science for better or for worse (OECD, 2010a). Sometimes students prefer not to use technology based on their personal interests and motivations (Beckman, Bennett, & Lockyer, 2014).

Two of the three biology teacher respondents commented on the challenges they faced when they were issued an Apple MacBook® after being used to a PC. Both physics teachers remarked on the laptops being enablers, allowing them to “use a wider set of tools” and that they “help if you need to show dangerous experiments or to provide other resources.” Unlike tthe students none of the physics or biology teachers mentioned laptops being distracting; for example, “People use Facebook a lot (but not me), it is very distracting for them.” None of the teachers used strong adjectives, positive or negative, such as *very*, *major*, *a lot* or *extreme*; they were either neutral, softly positive, or softly negative, such as “the intrinsic motivation to achieve a personal best is independent of the use of technology” [Biology teacher].

Analysis of curricula. In analyzing the respective physics and biology curriculum documents we discovered some stark findings. Both the physics and biology syllabuses had identical guidelines on the integration of technology in the *course structure, skills-conducting investigations, key competencies* and *domain Skills* (see Appendix).

In fact, the domain Skills, that is, course outcomes including practical skills, were identical in physics and biology for both Preliminary (Grade 11) and HSC (Grade 12), with five inclusions for the integration of technology. Both syllabuses included the same emphasized generic statement in key competencies: “During investigations, students use appropriate information technologies and so develop the key competency of using technology” (Board of Studies NSW, 2009a, p. 18; 2009c, p. 17). Given these identical curriculum outlines the respective technological activities recommended or mandated to the physics and the biology teachers and students in the domain Knowledge and Understanding might have been nearly identical, albeit within their respective curriculum contexts. However, this was not the case at all.

Within the domain Knowledge and Understanding, the respective syllabuses specified what students *learn* and what they *do*. In the physics syllabus there were eight specific mentions of the use of technology: two mandating the use of simulations (along with data-loggers and computer analysis in one instance); two suggesting the use of simulations; three suggesting a generic use of technology—for example, “alternate computer technology” (usually best achieved with simulations, such as replicating a cathode ray oscilloscope)—and one recommending data-logging.

In biology, despite all of the references in the course outline, even mentioning data-loggers, the syllabus made no specific mentions of the use of technology, even while specifying what students should learn and do. Given that both syllabuses were originally written at the same time in 2002 and the various technologies were already commonplace in the teaching of all science subjects, this finding raises questions around the consistency of the curricula and the syllabus writing.

Discussion

Teaching and learning have been found to benefit from the affordances offered by 1:1 laptops (and technology, in general) within some subjects more than others; for example, science over mathematics (Ainley, Eveleigh, Freeman, & O'Malley, 2010; Dunleavy & Heinecke, 2008) and physics over biology and chemistry (Crook et al., 2015). Within this paper we have established the differences in practices by physics and biology, as well as teachers and students, and unearthed contributory factors to these differences in the form of the respective curriculum requirements.

From the analysis of the uses of technology by the teachers and students in physics and biology, the biology teachers may not appear to have been engaging themselves or their students in the use of the 1:1 laptops in the classroom compared to physics teachers and students. However, it is quite apparent that the biology syllabus does not mandate or even recommend any specific uses of technology, whereas the physics syllabus does.

The physics syllabus specifies the use of simulations in student learning and, consequently, the physics teachers and students reported more use of simulations and similar technologies such as science software and spreadsheets than did their biology counterparts. Strictly speaking, the biology teachers engaging themselves and their students less with technology was not so much neglect on the part of the teachers but, arguably, a missed opportunity on the part of the biology curriculum writers. The biology teachers were merely doing what they were mandated to do regarding the use of technology, but probably with the conspicuous pressures of standardized external examinations, no more.

The specifying of simulations and data-logging in the physics curriculum and the reports of more frequent use of simulations, spreadsheets, and science software by the physics teachers and students would entail a greater knowledge of how to use each of these technologies and when to use them. That is, the teachers would require a certain amount of TCK; that is, an understanding of how technology and content influence and constrain one another (Koehler & Mishra, 2009). Teachers would require science specific technology knowledge (Khan, 2010) to apply this with their students.

TCK is the overlap between technological knowledge and content knowledge (see Figure 1). “Teachers need to understand which specific technologies are best suited for addressing subject-matter learning in their domains and how the content dictates or perhaps even changes the technology—or vice versa” (Koehler & Mishra, 2009, p. 65). This TCK appears to be lacking in the self-reports of the biology teachers and students and, most definitely, in the biology curriculum document.

The findings in this study highlight several differences between teachers and students in regard to their reported use of 1:1 laptops in their respective sciences. This finding was particularly the case regarding the use of simulations in biology. It has been hypothesized that any such misalignment between teachers and students, implying a more teacher-centered classroom, could be counterproductive to student learning (Crook et al., 2013). “The attitude of the educator towards technology use in the classroom is indicative of how well technology will be integrated in the classroom during instruction” (Kusano et al., 2013, p. 39).

As part of the $2.1 billion DER in Australia, all teachers, whatever curriculum specialism, are required to capitalize on the affordances 1:1 laptops offer for teaching and learning. Just because a curriculum syllabus does not mandate or recommend the use of technology does not mean teachers should opt out, particularly when students in their classes each have their own laptops. This imperative upon teachers has never been more acute as more and more schools move to a parent-funded bring-your-own-device model, as is the case across much of Australia since the end the federally funded DER (Digital Education Advisory Group, 2013). Detailed specification of technology within curriculum documents is unlikely to keep up with rapid technological developments, so relying on specification within curriculum documents to ensure appropriate integration of current technology within classrooms may be unreasonable.

Australian industry is currently bemoaning the lack of science and technology skills within the workforce, and there are calls for all levels of national policy and practice to address this need (Australian Industry Group, 2013). ICT is acknowledged within the national Australian Curriculum as an across-curriculum general capability but, as seen here, subject/disciplinary variations and disparities exist between teachers' and students views' of how ICT is implemented in classrooms.

TPACK

Providing an interpretive framework, TPACK was used to make sense of the laptop use of the teachers and students and the technology inclusions found in the curriculum documents and to locate them within the various facets of TPACK. In other words, both the questionnaire responses of teachers and students and the curriculum documents were examined to see what elements of TPACK were evident. The physics curriculum document and consequent classroom practices incorporated far more TCK than did those in biology.

Koehler and Mishra said that "teachers need to master more than the subject matter they teach; they must also have a deep understanding of the manner in which the subject matter (or the kinds of representations that can be constructed) can be changed by the application of particular technologies" (Koehler & Mishra, 2009, p. 65). The physics curriculum document facilitated specific TCK and TPACK as a whole by articulating *what* and in some cases *how* technology can be used. However, the same cannot be said for the biology curriculum document. This delicate interplay between teaching practice and curriculum documentation cannot be understated.

Simulations

Simulations are a particular theme of the findings in this study. In the analysis of the curricula the use of simulations was an explicit difference between physics and biology. In the analysis of the teachers and students in physics and biology, differences also existed in the self-reported uses of simulations between the subjects and between the teachers and students. In a previous study most science teachers reported using simulations in their teaching, but far fewer students reported using simulations in their learning (Crook & Sharma, 2013). "Carefully developed and tested educational simulations can be engaging and effective. They encourage authentic and productive exploration of scientific phenomena, and provide credible animated models that usefully guide students' thinking" (Wieman et al., 2008, p. 683).

Opportunity exists to integrate simulations in science teaching (Khan, 2010), learning (Kay & Knaack, 2007), and assessments (Quellmalz et al., 2012). In a report from the OECD (2010b), one of the conclusions was that the use of simulations in science "highlights how technology can improve the teaching and learning process by enabling pedagogical approaches that are impossible or more difficult to facilitate without the use of technology" (p. 151). Examples would be using the Thomson experiment simulation on the Australian Multimedia for Physics Students website (http://www.hscphysics.edu.au/resource/template.swf) if one lacked the required equipment or skills to set up the equipment or using the simulation on the PhET website (http://phet.colorado.edu/en/simulation/mri) to manipulate the radio-frequency in an MRI scanner to cause the nuclei in brain tissue to resonate.

In the same vein, simulations empower teachers and students to engage in virtual experiments that would be too dangerous to do in real life (Guzey & Roehrig, 2012; Zucker & Hug, 2008); for example, manipulating control rods in a nuclear reactor, as simulated on the Scootle website (http://www.scootle.edu.au/ec/viewing/L48/index.html).

Professional Development

For both preservice and practicing teachers, the professional development around the integration of technology in teaching science is of paramount importance, with amplified challenges due to the ever-evolving nature of technology (Guzey & Roehrig, 2012; Jimoyiannis, 2010).

The findings of this study reveal important lessons for preservice teacher training and the professional development of practicing teachers. Preservice and professional development for science teachers should include analysis of the TPACK framework, thereby making teachers more aware of the entire model and empowering them to be more balanced in their approach. Equally, preservice training and professional development should include an additional focus on TCK to assist teachers in their understanding of the references to the integration of technology in curriculum documents (e.g., junior science and senior biology), just as we have undertaken in this study.

Comparing curricula and understanding the differences can only empower future teachers. So, too, can an abstract understanding of the role of technology within teaching and learning. While ongoing development of specific technology skills will always remain a challenge, providing teachers with the TPACK framework with which they can reflect, analyse, and understand their own practice provides potential for long-term, self-driven, needs-based professional development.

In order for any professional development programs to have a significant impact on student science inquiry learning, they must be sustained over several years (3 to 5 to achieve the desired outcomes; Gerard, Varma, Corliss, & Linn, 2011; Towndrow & Wan, 2012). However, the development of teachers is not solely reliant on formal professional development. The same generic formal professional development around using 1:1 laptops with a class of students was made available to all teachers in this study as part of CEO Sydney Southern Region, plus some science-specific professional development around the use of data-loggers, but no formal professional development around the integration of technology was available to the physics teachers but not to biology teachers.

Given the mandate from the curriculum documents, the physics teachers must have received greater preservice training or networked and taught themselves over time how to integrate technology into their teaching, relying on self-direction, collaboration, and metacognition. Subject/disciplinary skills and cultures may also have a role to play in the integration of technology within schools.

Limitations of the Study

While drawing on the strengths of mixed methods, this study also had several limitations. Analysis of the qualitative comments was limited by the very low response rate and, accordingly, the content analysis also had limited scope. A deeper analysis could and should have been conducted had the response rate warranted it. These points are somewhat countered by the high student and teacher response rate in the technology checklist data and by the fact that we analyzed the curriculum and syllabus documents to provide a fuller account of classroom practice.

Recommendations

We offer four recommendations:

- Curriculum writers should more consistently promote evidence-based effective TPACK in curriculum documents, particularly TCK, which is often lacking.
- Teachers, schools, and ultimately, school systems should move beyond the mandatory curriculum content and also capitalize on the opportunities afforded by a 1:1 laptop environment, such as engaging students in simulations for firsthand investigations.
- Preservice teacher training and teacher professional development should empower science teachers in the effective use of technology in the classroom to enrich scientific inquiry.
- Further research should examine TCK and TPACK as a whole in preservice teacher training and teacher professional development.

Capitalizing on the potential of 1:1 laptops and technology, in general, not only to benefit students' learning in science but also to prepare students for the workforce and life (U.S. Department of Education, 2010), needs to be reinforced in every way by curriculum documentation, preservice training, teacher professional development, and school and school district culture. However, given the rapidly changing nature of technology, up-to-date explicit documentation in curriculum documents may not be feasible. Statements of principle are needed in formal curricula and syllabuses, and these principles should be supported by other, more updateable, supporting documentation to ensure timely and consistent best practice.

TPACK holds potential for helping teachers develop understanding of how technology can be integrated into teaching and learning, regardless of the shifting technological capabilities and their required skills. We suggest two overarching mantra for all science teachers, whichever the subject discipline:

- It is in the best interest of science teachers to "focus on teaching approaches that yield high rates of student success and exploit learning technology" (Fraser et al., 2014, p. 2).
- Science teachers should not only "be able to use the latest tools and technologies with their students, but they also need to take advantage of the latest research on learning, pedagogies and practices" (OECD, 2014, p. 3).

Conclusion

Given the resources invested in digital technologies in schools, we set out to investigate if such technologies made a difference to student learning and how they were used. The answer to the former question was yes, although this result varied by subject (Crook et al., 2015). The answer to the latter is reported in this paper. Referring back to the original research questions (a) we have found that physics teachers and students engaged in more higher order activities such as simulations, spreadsheets, and science software, compared to their biology counterparts; (b) although the students' comments perceived a negative impact and the teachers had less extreme views, the samples of respondents who commented were too small to draw any definitive conclusions; (c) fundamental differences exist between the physics and biology curriculum documents regarding mandates and recommendations around the use of technology, and these differences directly correlate with the differences found in the first research question; (d) the differences identified can be framed in terms of TPACK, with the physics curriculum and, consequently, the reported teaching and learning in physics containing more TCK.

Our perusal of curriculum documents suggests that technology may have been incorporated in an inconsistent, topdown manner. The findings of this study highlight the need to ensure that curricula embed and capitalize on the affordances offered by technology at all levels and in a systematic manner. The goal of researchers, teacher educators, and curriculum writers should be "to help teachers become aware of the full range of possible curriculum-based learning activity options and the different ways that digital and non-digital tools support each" (Harris et al., 2009, p. 411).

Locally in Australia, a unique opportunity to address this issue is provided within the new Australian Curriculum: Science. However, even though the *ICT General Capability* has been included in all of the curriculum documents so far released (science, mathematics, English and history), a disparity in the integration of technology already exists between these curricula (ACARA, 2011a; Board of Studies NSW, 2012). Given the recent consultations regarding the proposed directions for new senior science syllabuses (Board of Studies NSW, 2014), a consistent approach and collaboration must be fostered between the curriculum writers of each of the sciences. A considered and coherent, evidence-based approach to integrating technology into all curricula is necessary, since "excellent teaching can be enhanced with thoughtful consideration for the tools employed" (Yerrick & Johnson, 2009, p. 306). Schools and education systems need to be proactive in this regard. They cannot afford to treat technology as an optional toy on the side.

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Appendix
References to Technology in Board of Studies NSW Physics and Biology Syllabuses

(pdf download)

Appendix
References to Technology in Board of Studies NSW Physics and Biology Syllabuses

Section	Physics[a]	Biology[b]
Course Structure	Practical experiences should emphasize hands-on activities, including (p. 9): • undertaking laboratory experiments, including the use of *appropriate computer-based technologies* • research, using a wide range of sources, including print materials, the *Internet* and *digital technologies* • using *computer simulations* for modelling or manipulating data • using and reorganizing secondary data • extracting and reorganizing information in the form of flow charts, tables, graphs, diagrams, prose and keys • using *animation*, video and film resources to capture/obtain information not available in other forms	Practical experiences should emphasize hands-on activities, including (p. 9): • undertaking laboratory experiments, including the use of *appropriate computer-based technologies* • research, using a wide range of sources, including print materials, the *Internet* and *digital technologies* • using *computer simulations* for modelling or manipulating data • using and reorganizing secondary data • extracting and reorganizing information in the form of flow charts, tables, graphs, diagrams, prose and keys • using *animation*, video and film resources to capture/obtain information not available in other forms
Skills - conducting investigations	increasing students' skills in performing first-hand investigations, gathering first-hand data and accessing and collecting information relevant to physics from secondary sources *using a variety of technologies* (p. 13)	increasing students' skills in performing first-hand investigations, gathering first-hand data and accessing and collecting information relevant to biology from secondary sources *using a variety of technologies* (p. 14)
Key Competencies	During investigations, students use appropriate information technologies and so develop the key competency of ***using technology*** (p. 17)	During investigations, students use appropriate information technologies and so develop the key competency of ***using technology*** (p. 18)
Domain: Skills	Preliminary [c] (pp. 18-19)/HSC [d] (pp. 38-39) students: 11.1 identify data sources to: e) recommend the use of an *appropriate technology or strategy for data collection* or gathering information that will assist efficient future analysis 11.3 choose equipment or resources by: c) *identifying technology* that could be used during investigating and determining its suitability and effectiveness for its potential role in the procedure or investigations 12.2 gather first-hand information by: a) using appropriate data collection techniques, *employing*	Preliminary [c] (pp. 19-20)/HSC [d] (pp. 36-37) students: 11.1 identify data sources to: e) recommend the use of an *appropriate technology or strategy for data collection* or gathering information that will assist efficient future analysis 11.3 choose equipment or resources by: c) *identifying technology* that could be used during investigating and determining its suitability and effectiveness for its potential role in the procedure or investigations 12.2 gather first-hand information by: a) using appropriate data collection techniques, *employing*

	appropriate technologies, including data loggers and sensors 12.3 gather information from secondary sources by: a) accessing information from a range of resources, including popular scientific journals, *digital technologies and the Internet* 12.4 process information to: c) best illustrate trends and patterns by selecting and using appropriate methods, including *computer-assisted analysis*	*appropriate technologies, including data loggers and sensors* 12.3 gather information from secondary sources by: a) accessing information from a range of resources, including popular scientific journals, *digital technologies and the Internet* 12.4 process information to: c) best illustrate trends and patterns by selecting and using appropriate methods, including *computer-assisted analysis*

Preliminary Domain: knowledge and understanding	The wave model can be used to explain how current technologies transfer information
	• Students: perform a firsthand investigation to observe and gather information about the transmission of waves in:
	    o slinky springs
	    o water surface
	    o ropes
	    o *or use appropriate computer simulations* (p. 22)
	• Students: perform a first-hand investigation to gather information about the frequency and amplitude of waves using an oscilloscope *or electronic data-logging equipment* (p.22)
	Features of a wave model can be used to account for the properties of sound
	• Students: perform a first-hand investigation and gather information to analyze sound waves from a variety of sources using the Cathode Ray Oscilloscope (CRO) *or an alternate computer technology* (p. 23)
	• Students: perform a first-hand investigation, gather, process and present information using a CRO *or computer* to demonstrate the principle of superposition for two waves travelling in the same medium (p.23)
	Series and parallel circuits serve different purposes in households
	• Students: plan, choose equipment or resources for and perform first-hand investigations to gather data and use available evidence to compare measurements of current and voltage in series and parallel circuits in *computer simulations* or hands-on equipment (p. 28)
		none

HSC Domain: knowledge and understanding	The Earth has a gravitational field that exerts a force on objects both on it and around it • Students: perform an investigation and gather information to determine a value for acceleration due to gravity using	none

	pendulum motion *or computer-assisted technology* and identify reason for possible variations from the value 9.8 ms^{-2} (p. 41) Many factors have to be taken into account to achieve a successful rocket launch, maintain a stable orbit and return to Earth • Students: perform a first-hand investigation, gather information and analyze data to calculate initial and final velocity, maximum height reached, range and time of flight of a projectile for a range of situations by *using simulations, data loggers and computer analysis* (p. 42) The study of binary and variable stars reveals vital information about stars • Students: perform an investigation to model the light curves of eclipsing binaries *using computer simulation* (p. 64)	

[a] Physics syllabus (Board of Studies NSW, 2009c)

[b] Biology syllabus (Board of Studies NSW, 2009a)

[c] Preliminary course studied in grade 11

[d] HSC course studied in grade 12