Where are the learning spaces on the scientific inquiry landscape?

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Today's science graduates are more likely to become scientists without postgraduate research training, yet they seldom possess the skills to work as scientists. There is therefore a need for undergraduate students to not only learn scientific concepts, but also be able to inquire using scientifically sound methods. This ALTC funded project has investigated how Australian university educators are teaching scientific inquiry and what roles educational technologies play. A range of approaches for teaching scientific inquiry have been identified. Similarly, technology has played diverse roles in these teaching activities. In the Australian context, we have technologies affording the following learning experiences: guided learning spaces; virtual learning spaces that facilitate communication; and giving students exposure to the technologies used by professional scientists. There are, however, various reasons why educators do and do not choose to embrace educational technologies in their teaching of scientific inquiry. This paper reviews educators' choices and thus questions the perceived advantages and disadvantages using technologies to teach scientific inquiry.

Introduction

Publications on learning spaces typically start with discussions of people's environments for learning and then quickly advance to examining the influences technologies have on them. After declaring that "learning spaces are not mere containers for a few, approved activities; instead, they provide environments for people" (Brown and Long 2006, p 9.1), the authors go on to list three major trends in learning spaces, all of which are heavily influenced by the presence of technology. Similarly, Radcliffe (2008) offers a design framework where pedagogy, space, and technology are interconnected. In this way, he suggests: the intended teaching strategies affect the technology and space used; and technology can in turn suggest pedagogical improvements.

At the same time, there are growing concerns in Australia that higher education will be unable to meet future demands for scientifically skilled graduates. A cyclic decline is occurring where there is both a shortage of skilled science teachers, to inspire high school students, and fewer students choosing to study science at university. The primary goal of our project therefore has been to identify how educational technologies are and can be used to enhance students' scientific inquiry skills. The emphasis in this paper is on how these educational technologies differ in the types of learning spaces they provide.

The issues presented in this paper were inspired by a comment from one of the educators interviewed as part of the project and the assumptions her statement entailed. When asked if she was using any educational technologies in her teaching, she replied that she was not because she needed to be responsive to the students, that inquiry occurs at different levels and that she has to be responsive to those different levels in her teaching. This led to questions of whether technology inhibits or promotes the ability to be responsive to student needs when the aim is to teach the tacit knowledge that scientific inquiry skills require.

This paper argues that the educational technologies for teaching scientific inquiry provide various types of spaces. Firstly there are two contrasting trends. One is to provide a highly guided environment for learning specific content where there is little intrinsic ability for educators to be responsive to diverse students' needs. The other is to provide virtual spaces where the content is not necessarily build into the technology solution. Instead the space is designed for students and educators to interact and hence allow educators to be more responsive. Thirdly, there is a trend towards providing students with the opportunity to practice using technologies that are used by professional scientists in their discipline.

Background

Traditionally, the path to becoming a practising scientist was one of an extended, individual apprenticeship as a PhD candidate. Unlike studying science, becoming a scientist has required much more than acquiring a knowledge system, but also plenty of tacit, practical knowledge and experience of many recipes and techniques (Charlesworth, Farrall, Stokes and Turnbull 1989). The relationship between a PhD candidate, the supervisors, and the associated research atmosphere has been the preferred environment for such apprenticeship models.

More recently, however, the expansion in higher education has forced the tertiary sector to re-evaluate the way it trains researchers. A PhD is still associated with the pathway to "academic science", which is based on the discipline-based, research practices of European and American Universities (Whitley 1984). Over the last 30 years, however, there has been an expansion into industry- and state-based science. In this way, the work of scientists is heavily influenced by the goals of the employing organization which may be grounded in meeting economic, medical and social objectives (ibid). The trend has accordingly opened up broader employment opportunities for graduates, and this means that graduates are frequently being employed without having completed the lengthy apprenticeship that postgraduate research offers (Harris 2007). It therefore becomes the responsibility of the undergraduate curriculum to not only teach scientific knowledge, but also impart the more tacit aspects of being a scientist.

In this way, teaching scientific inquiry skills has become a more important priority for undergraduate courses. This coincides with progressions in general learning theory towards a constructivist paradigm where understanding, discovery, and the ability to criticise information are becoming preferential to memorization and recall (Brown 2005).

At the same time, there is a trend in the last decade where learning spaces are being seen as spaces for learning that extend beyond the classroom. With the advances in technology that allow interactions with learning materials and peers at mobile locations, "educators have an important opportunity to rethink and redesign these non-classroom spaces to support, encourage, and extend students' learning environment" (Brown 2005, p. 12.3).

The undergraduate science curricula, however, are challenged in the Australian context by large student cohorts, high student-educator ratios, limited time and resources and diverse student cohorts. Large cohorts make it challenging for educators to provide individualized and equitable feedback and help. Moreover, practical and laboratory classes use significant resources, including equipment, specialized venues, consumables, and educator and support staff time. Finally, students bring varied prior experiences, abilities, skills, motivations and goals to the classroom.

Given these challenges, the question arises as to how educational technologies are being appropriately used to teach scientific inquiry skills. Computers have been utilized for decades to engage students in scientific inquiry activities. Such approaches include: simulations where natural phenomena are represented; support tools to help students organize, visualize, and interpret data; and collaborative tools which enable students to communicate and share information. There has, however been little research conducted into whether such activities are geared towards teaching scientific inquiry skills and what activities are currently taking place in Australia. Moreover, anecdotal evidence suggests that many science students at tertiary level in Australia find it difficult to grasp the notion of a process that guides the progression of scientific inquiry.

Our project therefore aims to obtain a picture of how educational technologies are being utilized to teach scientific inquiry skills to bioscience undergraduate students. The emphasis of this paper is to study the range of learning spaces (or environments) that are being offered to students. In this way, the intention is to reveal how educational technologies are being utilized to teach scientific inquiry skills in the biosciences.

For the purposes of this paper, we define educational technologies as technical resources which are utilized by educators with the aim of improving performance in students. This is a narrower definition than that offered recently by the Association for Educational Communications and Technology (AECT) where "Educational Technology is the study and ethical practice of facilitating learning and improving performance by creating, using and managing appropriate technological processes and resources" (Richey 2008, p. 24). We focus on the use of educational technologies as a resource that can be utilized for learning and teaching purposes. Software and hardware solutions primarily designed for professional use have been included, but standard office software, such as Microsoft Office and use of a digital camera have been considered a standard tool rather than an educational technology. Moreover the reflections here will place reduced emphasis on whether student performance is actually improving due to educational technologies, but rather concentrates on highlighting the range of approaches being taken with the aim to improve such performances.

Given the literary definitions of scientific inquiry vary (Bunge 1967; Chinn and Malhotra 2002; de Jong and van Joolingen 1998; Kim *et al* 2007; Wenning 2007), a versatile definition has been adopted for the purposes of this paper. Scientific inquiry is thus defined as referring to "to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work" (NRC 1996, p. 23). In attaining the views of science educators, the participants have highlighted various aspects of scientific inquiry in their teaching, so the scientific inquiry skills listed in this paper are grounded in the opinions of science educators.

Methodology and work undertaken

The project has adopted an exploratory and qualitative approach to determine the approaches that are being taken by educators towards teaching scientific inquiry skills. Snow ball sampling has been used which began with four of the team members (Elliott, Galea, Irving, and Johnson) each suggesting a handful of educators whom they were aware had been taking some innovative approaches to teaching scientific inquiry, which led to further suggested contacts. Moreover talks and posters were presented by team members at various conferences and meetings early in the project and these were designed to promote awareness of the project and invite educators to participate. As a result, we gathered a list of approximately 40 educators, 17 of whom asserted they teach scientific inquiry skills and agreed to describe their approaches to teaching scientific inquiry in detail. These educators are from nine universities across four states and territories and are from a broad range of bioscience disciplines, including agricultural sciences, biology, biochemistry, immunology, microbiology, pharmacology, physiology, and zoology. The overall strategy was therefore to attain a broad range of approaches to teaching scientific inquiry skills rather than a statistically representative sample of popular trends.

In this paper the use of educational technologies for teaching scientific inquiry is discussed as a phenomenon. In this way, the primary interest was to find out how the educators perceive educational technologies to be useful in what they aim to teach. Accordingly, any evidence that educators reported of their success or challenges forms supporting evidence, but the particular stage of the project included in this paper places less emphasis on primary evidence of whether the teaching improved student performance.

Description of work undertaken

Data collection began with the intention to recruit via telephone and choose participants who were endeavouring to teach scientific inquiry. Contact began with an email and attached plain language statement to alert participants to expect a phone call. The plain language statement suggestively defined scientific inquiry skills as including "skills like the following … (1) Problem analysis; (2) Hypothesis formulation; (3) Prediction of logical consequences; (4) Inquiry planning; (5) Hypothesis testing (collecting, analysing, and interpreting data); (6) Drawing conclusions; (7) Communicating results." As the exploratory research approach evolved, however, it was decided that reduced emphasis should be placed on this definition when talking to educators and instead that the educators themselves be prompted to offer their own definition of scientific inquiry skills as applicable to their discipline.

Phone conversations asked educators what approaches they were taking to teaching scientific inquiry skills to their students. If the educators asked what was meant by scientific inquiry, the question was reflected back for them to define before progressing. Most participants then offered more than one approach and the non-quantitative and non-random sampling meant that they were free to mention and comment upon approaches being taken by their colleagues and associates as well. Educators were asked to describe the approach with the interviewer prompting for details on: discipline; cohort; year level; student numbers and student educator ratios or indications of the educator time required per student; learning objectives and motivations for taking this teaching approach; method and details of learning design; any evidence of success in achieving the learning objectives; and the presence or absence of educational technologies in the approach.

The exploratory approach taken did endeavour to uncover as many different approaches as possible where educational technologies were being utilized to teach scientific inquiry skills. The emphasis, however, was not to exclusively report on incidences where technology had been utilized, but also to consider the bigger picture of educators' attitudes to adopting technical resources for the task. In this way, the attitudes educators had to avoiding the use of technologies were as equally interesting as the reasons they chose to exploit technologies.

As telephone correspondences accumulated, it became apparent that many educators were giving a large amount of detail over the telephone complemented by teaching documents and recordings. So while the intention had been to gain further data from most via face-to-face interviews, this was found to be less important than first anticipated. Six face-to-face interviews have been conducted, but many details have also been collected by telephone with supplementary data from student handouts, practical manuals, and recordings of lectures.

Telephone interviews were recorded using field notes that were sent back to the participant for verification. Face to face interviews were audio recorded. All data has been loaded and analysed using NVivo 8 (Software by QSR International) to identify themes. The nature of NVivo is such that it encourages the user to take a grounded theory approach (Glaser and Strauss 1967) to analysing the data, so the process of analysis identifies themes that are intrinsic to the data. This process, however, has also been influenced by the background theories that the research team has brought to the project. Namely, the project started with a particular list of skills that constituted scientific inquiry skills. Similarly, theme names and groupings have been impacted by recent publications that emphasise the development of scientific inquiry skills in first year and in the laboratory context (Adams 2009; Rice, Thomas and O'Toole 2009; Wilson 2008).

Results

Definitions of scientific inquiry varied amongst participants and ranged from asking questions and formulating hypotheses, to thinking critically and being able to use laboratory equipment. The following, however, will report on the aspects of scientific inquiry that the participating educators listed as learning objectives and motivations. The listings are reasonably consistent with Wenning's (2007) stages of scientific inquiry. The participating educators listed the following learning objectives:

- Problem analysis and other reasoning skills are required before carrying out any tests. This includes, finding information, formulating hypotheses, and designing experiments;
- The ability to carry out experiments, including technical competency with equipment, generating, observing and interpreting data, hypothesis testing and statistical analysis;
- Drawing conclusions, including when there is no one right answer. This includes thinking critically;
- Collaboration and communicating results incorporates examples where students are required to present their thinking or their work to each other and/or the educator; and
- Overall notions of the process of inquiry. These include approaches where students are treated as authentic scientists, taught scientific inquiry as a process, or encouraged to cyclically refine their approach.

Correspondences with participants revealed various strategies and tactics to teaching scientific inquiry. The following illustrates some highlights of participants' approaches:

Planning an inquiry

Skills included problem analysis, finding information and designing an experiment. Where the preparatory stages leading to performing an experiment or hypothesis were an objective, educators were utilizing technology to either promote discussion between students or requiring them to search through information that professional scientists also use. Online discussion groups were employed by one educator to get students to have an open ended discussion about a concept: As was stated in lectures:

> So in your debate groups I've given you a discussion topic and I want you to talk about this issue. And I've given you a few ideas to start with. So I'll show you what that is and then you can ask any questions you like. And then I will pretty much step out of the process and only jump in if there is a really open ended question you want to ask … I want you to

> speculate. I want you to think broadly. I want you to be specific but think broadly about all the different things that need to happen for that to occur.

Other educators required students to access online databases or perform literature searches to find information. Exposure to interacting with online databases (which hold biological data such as genetic sequences) has been highly guided by the educators interviewed for our project, where the locations to access are given to the students and the formats of the files the students are exposed to are also explained.

Searching for literature can take many forms including the fairly classic teaching approach of requiring students to find and review an article. One of the participants actually turns this on its head by giving students the key finding of a paper and requiring the students to find the paper from only this information. As written in the assignment sheet:

> Each student is provided with a statement of experimental results reported in a contemporary research paper. Students need to use the PubMed data base and seek out the reference. Sample statements are of the form: X binds to Y; X does not suppress Y through Z; X activates Y; X enhances Y; X can inhibit Y in mice. Students are then instructed to: List key words searched and number of hits; show how you have combined searches. Give the journal reference that contains the statement. If you find more than one reference, choose the earliest one.

These latter two examples make use of technology that was not necessarily designed for educational purposes, but expose students to authentic information that a practicing scientist might use.

Laboratory experience

These included technical competency in the laboratory, generating and interpreting data, and testing. Experiences are simulated for a range of logistical reasons as well as in supporting face-to-face teaching. Simulations identified in our project teach students how to use equipment, such as a microscope, before they attended the laboratory, while others simulated an entire experiment. The latter allowed students exposure to experiments that could not be ethically or practically conducted in reality. Such topics include breeding human pedigrees, performing tests on human blood, and experimenting with biodiversity.

Teaching approaches with these learning objectives have included technologies that are designed for professional science laboratories. These included charting software that graph results in real time and allow the figures to be manipulated. Secondly students were guided through statistical software where they are expected to calculate the significance of their own laboratory results.

On the other hand, there were educators that specifically chose not to use technology when exposing students to experiments. As one educator explained, an ethics committee was trying to get her to run her animal behaviour experiment, which students had to design themselves, using video footage instead of real animals. The study of live animals for her, however, was about the fact that animals are unpredictable. She argued that the students need the real experience of seeing each others' animals behaving differently. Although not discussed with the educator, it follows that, even if a simulation were used with unpredictability built in, the unpredictability would be viewed by the students as something intrinsic to the simulation. There is then a second leap of association required for the students to consider it intrinsic to the animal.

Under this general category of laboratory experience, it seems appropriate to mention two other reasons educators have given for not using educational technologies in their teaching of scientific inquiry. The first was that they saw no need and had no real inclination towards engaging more technology in their classes. The second was the contention that educators may well find that educational technologies would enhance their ability to teach, but that they are too short of time to make the transition to a new method of teaching.

Drawing conclusions, thinking critically, and accepting that there is no one answer

In this category, technologies that facilitate communication start to feature more strongly than against the above mentioned skills. Both the online discussion groups and literature searches both feature under this category for a second time. In addition, there is a software solution, PRAZE, being developed that allows students to perform peer reviews of each others' work while handling the administrational logistics of matching reviews and keeping them anonymous (Mulder and Pearce 2007). In the discussion group example, students are required to make their own judgements on an open question and exposed to the fact that there is no one right answer to the question being asked. Again access to searching literature requires students to think critically once they have found the articles. The real presence, though, of technology at this point is minor.

Collaboration and communicating results

When this category is about communication, it may not be surprising that most of the technical resources in this category relate to communication. Again, the discussion group aids collaboration and PRAZE encourages communication.

One educator is also requiring students to create wikis of key concepts:

> I started to do the wikis because it seemed to me that students hate group work, … they really hated it and there had to be a way that would be fair to internal and external students. External students get very isolated … wikis to pull the two cohorts together … as a side issue they had to come up with a topic for their wiki … there had to be a lot of guidance because they were online and they found it very difficult. And I had to ban the internal students from meeting on campus … I made a lot of mistakes, but then once I got the rules right, it seemed to go okay. And they have to come up with a project, research it and then make a website.

For this educator, the approach only bordered on being a form of scientific inquiry. Her main aim with this exercise was really to remove physical location from consideration for a collaborative learning space.

On the other hand, one educator was using software to direct first year students through the Lab Tutor software which guided the information prac reports should include. Then in later years, students progress to writing their own research proposals and papers for assessment.

Authentic science and its ongoing, cyclic nature

Numerous educators had the objective of giving students access to authentic science. Educators wanted to expose their students to research that is currently taking place, explain how discoveries have been made gradually over time, and that science is not a list of facts but rather that each experiment leads to more questions. While this was their ongoing philosophy, the role of educational technology in enhancing the teaching of this was fairly minimal, though there was the occasional example found.

There was also an educator whose highly guided online tasks did include cyclic refining. That is, the students could modify variables, perform an experiment, and then refine the experiment further. The experiment was “one where you can generate endless pedigrees or endless blood groups” which effectively means they can keep refining their hypothesis.

Again, abilities to have online discussions were also set up as an opportunity for students to debate like real scientists. As stated in the lecture:

> You’re only just starting on the course of becoming a scientist. Most of you will be in one way or another a scientist at the end of this. Or we hope that you will be. So what you need to start doing is using some scientific principles to solve in this case a question that’s got no definite answer.

Similarly, the CASPiE model, offered through Purdue University, of involving students in the collection of data to be used in ongoing research has been adopted in a chemistry subject in Australia and the same principles could be introduced here and have been employed for bioscience projects outside Australia. Amongst many opportunities for students to play the role of real scientists, CASPiE involves NING, a Facebook-like application:

> … we set up a NING social site so students could actually exchange ideas with the US students if they wanted to. So they are aware that this is an international activity and if they wanted to they could engage or not engage with it …it’s invitation only .. so like facebook but not … it’s only the students in the CASPiE program

Given this approach was actually in chemistry and not the biosciences, we have not investigated this aspect any further. It has, however, great potential to be utilized in the biosciences.

Scientific inquiry as a process

Finally, there were three examples reported by educators where technology was employed to teach scientific inquiry as a process, though two of these are products developed by members of this project team. The two educational technologies by members of this project are Virtual Plant Pathology Lab and Virtual Laboratory for biochemistry students (Elliott, Sweeney and Irving 2008). Both these resources step students through a process of investigation whilst requiring them to enter information about the interim and final conclusions they have drawn.

The third approach was uncovered through interviewing participants and uses a tablet PC to introduce the process of inquiry as a flowchart. The tablet PC allows the educator to draw flowcharts from scratch using active suggestions from students in the lecture. At the beginning of the semester, she draws the first practical class as a flowchart in the lecture and simply requires students to copy the chart. From then on, however, the students are required to draw such flowcharts for every practical class and present them for a pass/fail inspection at the beginning of the laboratory class. By observing such a class, it was determined that the students put much more detail than required into these flowcharts and that they then carried out the laboratory class with very little need for confirmatory questions on the procedure which left the educator with more time to attend to coaching students' ability to interpret their results.

Discussion

When listing the learning objectives in their approaches, educators utilized various teaching contexts and resources. Some felt that scientific inquiry was predominantly taught in a laboratory environment while others discussed and displayed scientific thinking in lectures and tutorials. They therefore listed various forms of classroom based learning spaces. The main emphasis in this paper, however, is on the types of learning spaces that educational technologies have enabled and participating educators' reasoning on whether or not to use educational technologies to teach scientific inquiry skills.

The key offering this paper endeavours to make to educators, who wish to teach scientific inquiry skills to their students, is to differentiate between three trends in technology use that suggest three contrasting pedagogical strategies. The trends in technology are:

- Computer-based and online tasks that provide predefined guidance or scaffolding,
- Virtual learning spaces which provide little intrinsic content-specific guidance but rather enable interaction between students and educators, and
- The provision of authentic science technology and software that are used by professional scientists of the discipline, some of which provide virtual access to learning opportunities and others which enable learners to process data efficiently and comprehensively in the ways a professional scientist would.

Figure 1 displays various learning resources that are being utilized to teach scientific inquiry. Some of these learning resources are specifically named, software solutions that are either available or under development while others are general teaching tactics that have been implemented as course-specific software applications or general groupings of software. The learning resources are classed along two axes. The vertical axis is the scientific inquiry skills as derived from participants' reported learning objectives. The horizontal axis categorizes the three trends for learning spaces afforded by technologies.

The listed technologies on the left are solutions that provide an interface between student and information. The technical resources in this category typically either: model a transmission approach to learning where the goal is for the student to absorb information provided by the learning resource; or allow strongly guided interaction with scientific concepts. Nevertheless the learning space is one where interaction is limited to being between student and computer. While some further reading (both on and off line) may be incorporated, there is no provision within the solution for interactive communication with educators and other students. The advantage of these approaches is that the scientific concepts the students are exposed to when completing the core activity are limited and directed. They therefore offer a bounded, scaffolded learning experience.

On the right are resources which promote learning by facilitating communication. This is listed on the opposite end of the axis because there is little perceived overlap with the guided approaches on the left. These approaches have no specific scientific knowledge embedded in the resource. Instead the students

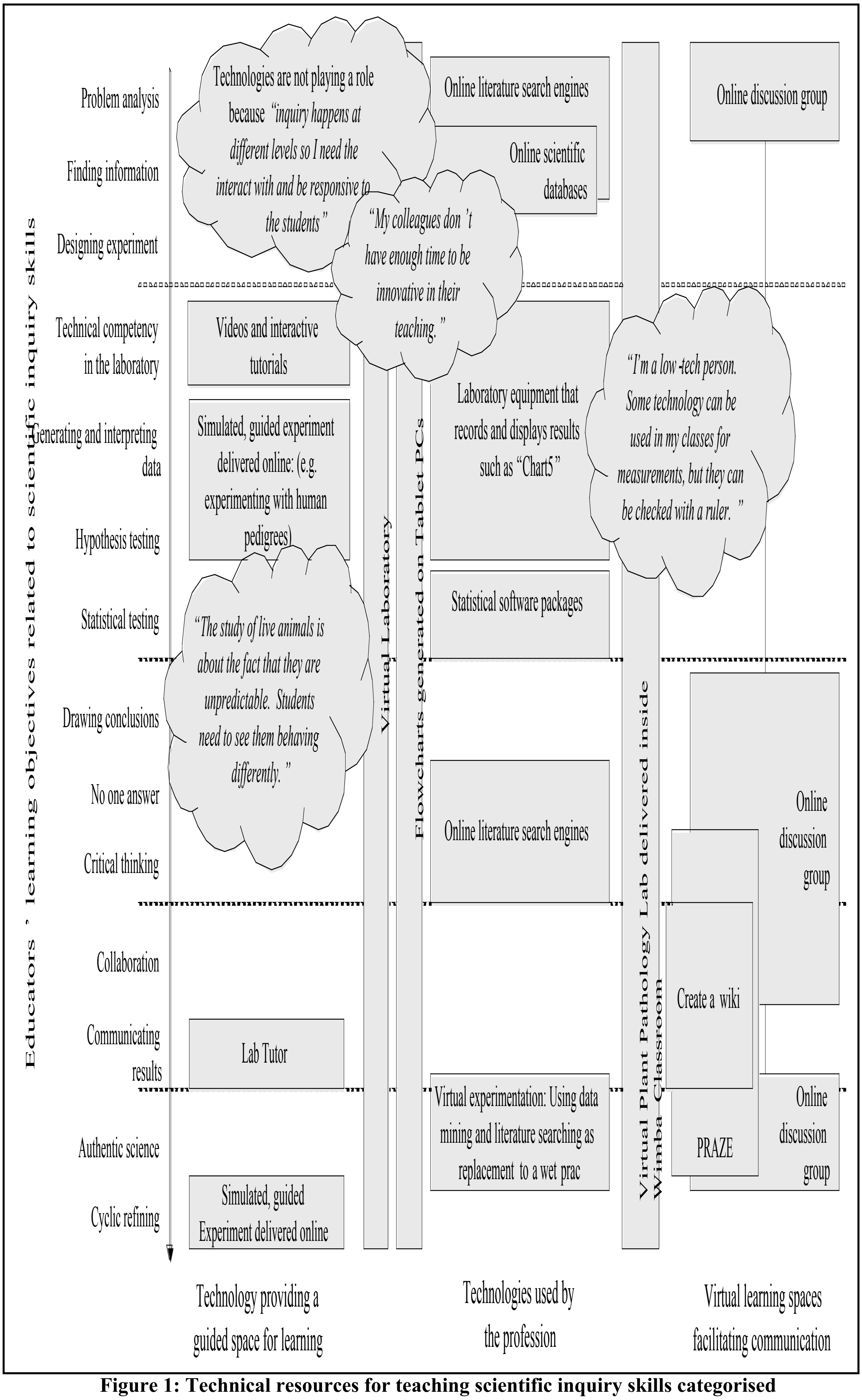

Figure 1: Technical resources for teaching scientific inquiry skills categorised against three identified trends in science learning spaces

are required to use the online space to be the providers and describers of scientific knowledge and reasoning. Here, the concepts that can be included are open-ended and the solutions are not assuming a particular level of prior knowledge. The main advantage is that they promote communication between students and educators. In this way they make more opportunities available for student peers and educators to be responsive to each other.

After some consideration, there has also been a middle category created for resources that enable students to mimic professional scientists. In these cases students are given access to information and technologies that aid scientific calculation. They have a little in common with the other two trends. In some cases, such as literature searching and data mining, the resources are providing access to virtual environments and information. In other cases, statistical packages and laboratory equipment displays effectively give students access to the scaffolding that professional scientists continually rely upon. Overall, however, these technologies are providing students with experiences of being graduate scientists.

Finally, there are also approaches denoted as long, thin boxes spanning all skills. These enable scientific inquiry to be taught as a process. It is no coincidence that these technical resources are also adjacent to technologies used by the scientific profession. This is because they perform the additional role of requiring students to think like real scientists. All three of these solutions are actually significantly guided with one also making use of communication technology. In this last case, the teaching resource has been embedded in Wimba classroom. The other two examples, however, do not facilitate virtual communication. Instead they use technology to enable students to think through processes of scientific inquiry and thus actively reason like scientists.

Conclusion

In teaching scientific inquiry skills, Australian educators have adopted various pedagogical strategies. Some require students to plan an inquiry or go about critically analysing information where multiple plausible answers are possible. Others give students access to laboratory experiences which may be at least partially simulated in a virtual environment. Some focus on requiring students to collaborate and communicate results or take part in authentic scientific research. In most of these cases, technical solutions form a tool for a subsection of the teaching approach. Though, in a few cases, educators use a single technical solution to teach scientific inquiry as a process.

Our research accordingly shows that learning spaces predominantly form tools for a teaching approach rather than facilitating a complete learning design. There were three main trends of educational technology use identified. Some technologies provide students with an individual learning space that gives high levels of guidance. Others expose students to software and experiences of a professional scientist. Thirdly, technology can be used to provide collaborative learning spaces where specific scientific concepts are not intrinsic to the resource.

There are also various reasons why educators have not adopted educational technologies to teach scientific inquiry skills. Some did not see the need or advantage. Others believe there is no substitute for authentic, first hand exposure to experimentation. Thirdly, educators can be too pressured by other requirements to think laterally about their teaching. Lastly however, some educators were of the opinion that educational technologies removed the ability for educators to be responsive to their students. Indeed such responsiveness is particularly important when the desired skills being taught are tacit.

This last assertion, however, is what this paper endeavours to dispel. After all, learning spaces and appropriate guidance from technology can give educators the strategic time to be more responsive to their students if utilized appropriately.

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