Journal of Information Technology Education: Innovations in Practice Volume 9, 2010

Didactics of Information Technology (IT) in a Science Degree: Conceptual Issues and Practical Application

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Executive Summary

Information technology has been transforming various disciplines of life sciences and physical sciences as a tool (for "doing" science) and a technique (for conducting experiments and creating models). This evolution in the application of IT in science demands that science students be equipped with appropriate IT skills and that the development of these skills should begin as early as possible in the program of their science studies. This article reflects on an enabling IT unit designed to develop IT skills among first-year students in a Specialist Science Degree at Victoria University in Australia; students in the Degree share a common first year and then choose a specialization, for instance biotechnology, chemistry, or ecology and environmental management. The article outlines the conceptual framework that underpinned the development, in particular the approach to making IT knowledge and skills relevant to students of different specializations, details the pilot implementation of the unit, and presents evaluation outcomes.

Keywords: IT skills, science degree, digital literacy, specialization, practical application.

Introduction

Universities in many countries have been reviewing the content and structure of their curriculum/programs to try to ensure that they are offering their students degrees that will equip them well for lives and careers in a 21st century world of global forces and rapid change and to promote their graduates' capacity to live and work successfully throughout the world. This process is evident in the US, UK, China, Hong Kong, Singapore, and in other countries, as well as in Australia. Universities across Australia have embarked on radical program reforms involving a reduction of discipline-based undergraduate offerings in favor of a much smaller number of broad undergraduate programs integrating the humanities and science; for instance, the University of Western Australia plans to cut its undergraduate programs from seventy to six by the beginning of the 2012 academic year; upon completion of a broad undergraduate degree, students can pursue specialized graduate programs. This is quite a change from the established format of Australian degree programs which tend to be quite discipline-specific throughout their duration; hence, students commence detailed subjects within their specializations in their first year of studies (unlike degree programs in the United States, where first year studies are more broadly based).

Editor: Eli Cohen

In a less radical way, LaTrobe University in Australia has rationalized its ten first year undergraduate programs in the Faculty of Health Sciences by creating a common first year for all the programs (McAlpine, Pannan & Fitzmaurice, 2008). Victoria University has introduced a similar curriculum reform by offering a Specialist Science Degree (Degree) to replace a number of current science degrees. The Degree includes a common first year and branches out into Degree specialisations in the second and third year; the specialisations include Biotechnology, Chemistry, and Ecology and Environmental Management. The first year of the Degree is designed to be rich in disciplinary breadth across the broad areas of the sciences, and the second and third year are designed to provide intense disciplinary depth and/or professional expertise.

Given that IT, or indeed computer science, underpins many of the scientific disciplines, the development of computing skills was included as a mandatory unit in the first year of the Degree. A unit of study is a set number of hours of study by students each week over the course of a semester. This decision was supported by Microsoft Research Cambridge's report "Towards 2020 Science" (Microsoft Research, 2005), which has strongly identified the importance of mathematical, quantitative and computational and IT skills to all students in science. The need for IT skills in students, including science students, is also supported by Dickerson and Green (2004) who found computer skills and high-level communications skills to be the most valued capabilities in new graduates; according to Dolton & Pelkonen (2007) both IT and communication skills carry positive wage premiums. Importantly, Kirby and Riley (2006) reported on a shift to value more highly the ICT skills acquired from schooling and work experience over those ICT skills that have been learnt on the job. This underlines the pivotal role of universities in ensuring that all graduates are equipped with a strong set of IT capabilities as well as discipline specific knowledge to be work ready.

Universities worldwide publicly state the skills and attributes that their emerging graduates are expected to possess (Treleaven & Voola, 2008). In Australia, publicly funded institutions are expected to articulate the perceived benefits of their respective programs and report annually to government upon the means through which they promote the development of these generic capabilities amongst their exiting students (Toleman, Roberts, & Ryan, 2004). For example, the Graduate Capabilities (GCs) Policy at Victoria University ensures statutory requirements are met through specifying a framework for all programs in which to embed the development of core graduate capabilities. According to the policy, in addition to their technical and field of study-specific knowledge and skills, a Victoria University graduate should also demonstrate a host of auxiliary skills including problem solving, communication, critical evaluation of information, and ability to work in teams, just to name a few; the development of these capabilities is expected to be incremental and context dependent. Hence, the development of the GCs is to be embedded in the discipline knowledge and skills.

While the list of desirable graduate capabilities included in the GC policy is quite comprehensive, it does not include any explicit reference to the acquisition and development of IT skills; this is an issue discussed by Miliszewska and Tan (2004) in relation to an earlier iteration of the University's Core Graduate Attributes Policy, and further elaborated on in Miliszewska, Venables and Tan (2009) with respect to the development of contextualized generic IT skills in students of a Science Degree. The following sections take this discussion further by reporting on the implementation and evaluation of an initiative that introduced essential IT technologies, tools, and skills to tomorrow's scientists.

The Conceptual Framework for a Common IT Unit

Recognizing the importance of IT and digital skills to model and solve problems within the science disciplines, an IT unit has been introduced to the common first year of the Science Degree. To define the breadth and nature of the IT unit, academics from the various specializations within the Degree were polled to identify the set of information literacy and competencies needed by their graduates. Upon analysis of the feedback, it was noted that a great deal of basic knowledge and skills, such as database searching, were seen as important for students, irrespective of their specializations. Likewise, the integration of information from various software sources, the effective use of Internet search engines, and software tools were similarly identified.

Collating these requirements into the unit content posed another challenge for its delivery. How best to cover the common content and instill essential generic skills, whilst maintaining its relevance and appeal to all specializations? The primary mandate of this IT unit was to complement the development of generic IT skills with a practical application of these skills in the various areas of students' intended specializations and future careers. To this end, the unit aimed to introduce students to the basic concepts, tools, skills, and competencies required of all scientists. The content included an overview of the Internet, characteristics and functions of browsers, Web design and authoring, resources on the Internet, using search engines effectively, use of technology in information gathering, storage and reporting, and online presentation. Importantly, students needed to develop an awareness and appreciation of the social, ethical, and intellectual property issues arising from the use of information technology within their disciplines and within society as a whole.

In the literature, context and relevance are considered essential to all learning, so students should engage in real activities that have purpose and meaning (Brown, Collins, & DuGuid, 1989; Sheard & Hagan, 1998). Drawing on this pedagogical facet for teaching using technology, Mishra and Koehler (2006) suggested that successful approaches should incorporate interesting and relevant examples. Their case studies revolved around authentic and loosely defined real-world problems to best engage students and enhance their learning experience. Likewise, the IT unit in the Science Degree was to incorporate within its practical component, topical problems related to the areas of biotechnology, chemistry, and ecology & environmental management.

The unit, through a mixture of lectures, laboratory sessions, competency-based modules, and inquiry-based projects, explored topics encountered in other first-year science units and drew on topical issues in science. Students were taught to use applicable IT tools in developing their analytical, problem solving, and writing skills. They had the opportunity to master a range of computing skills needed to work with spreadsheets, database management systems, and internet search engines just to name a few and, at the same time, relate those skills to various specializations within the Degree. For instance, practical work required students to create tables within discipline-specific Web pages; some students were asked to present carbon trading details in a table, alternatively others presented information about chemicals in the environment, or data about differing types of biological cells. Later in the semester, students were expected to research and author Web pages before building small-scale Web sites to display topical and discipline-specific information to a general audience. Through this experience, students came to appreciate the many social, ethical, and intellectual property issues emerging from the use of IT in their area of specialization.

Practical Application

Broadly speaking, the unit introduced students to computing, information management, and communication. Through the topic of the Internet, students studied search techniques, explored data, information and software availability and acquisition, evaluated data reliability, and identified and discussed ethical and social issues arising from computer use in society. In studying Web page design, students were introduced to good design principles and practice, accessibility issues, formatting elements, and mechanisms for user interactions. The major steps of Web site construction were studied, from project conceptualization through analysis, design, production, testing, and the ultimate launch; students constructed individual Web sites on their topic of choice.

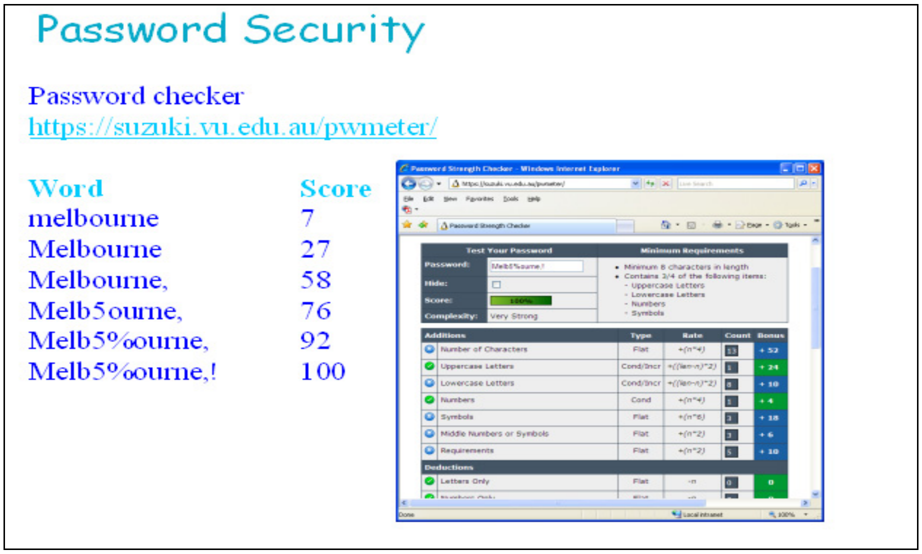

Figure 1. Screen shot of lecture material reinforcing the need for a strong password and its assessment by a password checker.

Due to the strong practical nature of the unit, the four contact hours per week were divided evenly between practical (laboratory) and theory (lecture) sessions. In fact, much of the learning was structured to first introduce students to key content through hands-on experiences and then reinforce it in the subsequent lectures. For instance, to illustrate the social responsibilities of computer users in an organization, students examined the Acceptable Use Policy (AUP) of Victoria University first during a practical session, followed by a lecture discussion; the policy stipulates, among other things, that students should maintain good password practices. So, in the practical session students were asked to test their own passwords for strength in a University authorized password checker, as illustrated in Figure 1.

This exercise proved very revealing and successful at the same time. It revealed that the students had been ignorant of the content of the policy, the terms and conditions of its application, and, most importantly, its impact on their own use of computers and the Internet. Having to check and score their passwords (in term of security) in a hands-on manner in the laboratory made the students aware of the policy in a realistic, accessible, and meaningful way. The subsequent lecture discussion was lively and engaged as the students regarded the policy through the prism of their earlier practical experience.

On other occasions, lectures introduced new concepts that were later reinforced in laboratory sessions. For instance, the creation and use of simple form elements in Web pages was introduced in a lecture and then followed up in practical sessions. This scheduling of learning experiences had another important aim: it made it possible to tailor the practical exercises to the discipline-specific need of the various student cohorts within the Degree. Figure 2 illustrates how the task of creating simple Web forms was customized for the Biotechnology, and Ecology and Environmental Management cohorts.

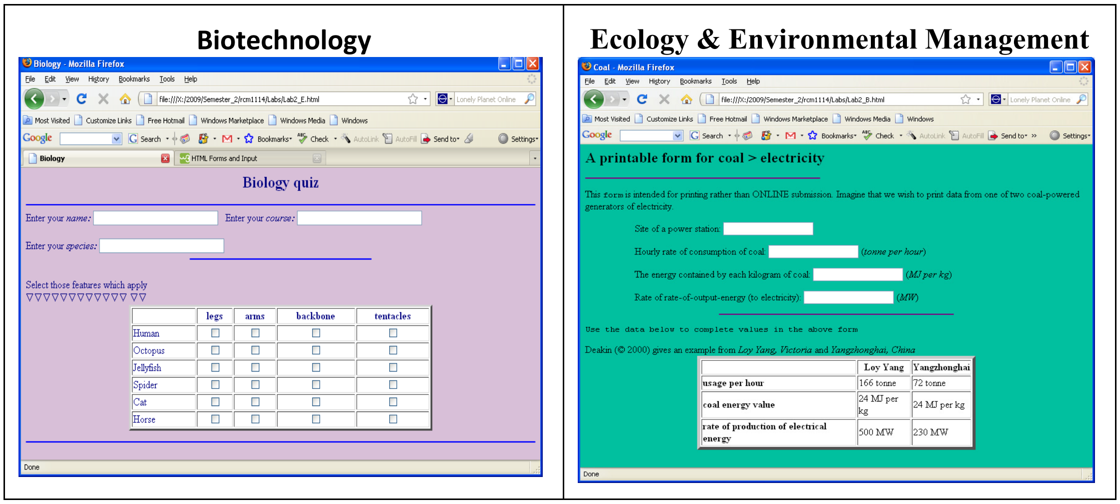

Figure 2: Practical assessment exercises on basic form elements contextualized to two different student degree specializations.

The content of the lectures and the practical work was intrinsically connected. Common proficiencies and skills were discussed and practiced, with illustrations taken from each of the separate specializations within the degree. To assist students in keeping track of these materials and competencies, each lecture concluded with a set of summary points and each practical session commenced with a detailed step-by-step listing of the skill sets to be achieved. Students found these summaries and outlines to be valuable in measuring their progress and preparing for assessments.

Assessment

Assessment of the unit comprised three assignments, worth 5%, 5%, and 20% of the final assessment respectively, and a final examination worth 70%. The first two assignments were formative, staggered throughout the unit, and provided regular feedback; the third assignment was a capstone task that involved the development of a Web site. The first formative assessment was paced to introduce basic elements of Web page production, including hyperlinks, images and forms, and viewing the result in a local web browser. The second formative assessment involved practising basic statistical manoeuvres on data that had been searched for, and downloaded from, publicly available databases. Once tabulated, the results were incorporated into more complex Web pages, which were formatted using external cascading style sheets and then uploaded to a Web server.

For the third assessment (a summative one), students needed to draw on the accumulated proficiencies gained in each of the practical sessions and the previous formative assessments. They needed to conduct a series of Web searches to identify a suitable topic within their area of science specialization that could be developed into a Web site of between six to ten pages. Once they had decided on a suitable topic, students proceeded to collect relevant information, bearing in mind the need to correctly reference the various materials and their respective sources, comply with copyright requirements, and avoid plagiarism. Students synthesized materials and information into categories to form a hierarchy that influenced their Web site designs. As well, students determined the style of their final Web site including details such as color scheme, relevant graphics, and text fonts and sizes before testing their Web sites in different browsers and varying resolutions. A detailed marking scheme accompanying the assignment specification outlined marking allocations for the various technical components; the technical components were generic and graded equally regardless of their discipline-specific implementation. The marking information assisted students in shaping and optimizing their solutions; they could decide on the inclusion of extra features to score bonus marks. Figure 3 presents examples of Web sites created by students from the various science specializations.

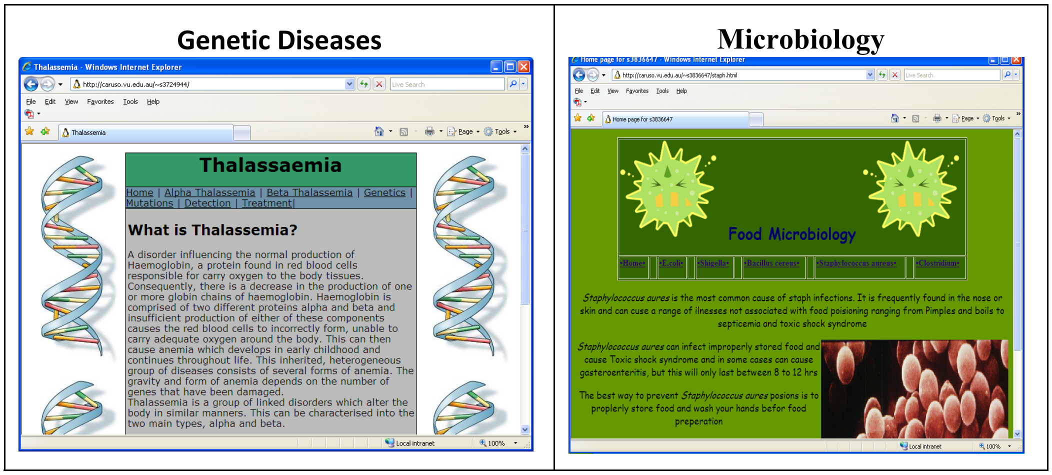

Figure 3: Example of student Web site development assignments.

The requirement of the third assignment to develop specialization-specific Web sites resulted in vigorous discussion during laboratory sessions as students "compared notes" with others from different specializations. Thus, students of different interests discussed and informed their classmates about their chosen topics. Collectively, the created Web sites helped illustrate the breadth of the specializations in the Degree and the fact that, despite their diverse disciplinary interests, students still demonstrated a common set of IT competencies achieved through studying the IT unit.

Evaluation and Discussion

Three different components were used to evaluate the impact of the IT unit on student learning outcomes: assignments, final examination, and a survey; this triangulation was aimed to facilitate validation of data through cross verification. The sections below outline the outcomes of the evaluation components.

Assessment Outcomes

The first formative assessment, in which students were expected to demonstrate their command of elementary IT skills, was scheduled early in the semester; this enabled provision of early feedback on student progress. Student understanding of early concepts was consolidated further in subsequent practical sessions and assessed in the second formative assignment. This strategy seemed to be effective, as the marks on the second assignment confirmed progress in student learning – they were consistent and even marginally higher from the respective marks on their first assignment, although the second assignment required more advanced knowledge and skills.

The quality of student final assignments further confirmed the value of step-by-step development of the practical competencies within the IT unit. Responding to the stimulus of an activity with purpose and meaning, many students were highly motivated and spent considerable time researching their topics and developing their Web site submissions. Many students took up the challenge of gaining bonus marks by implementing more advanced and sophisticated technical components; the marks on the final assignment, while reflective of the marks of the earlier assessments, were more related to the extra effort that the individual students put into their assignment work. Consequently and somewhat unsurprisingly, student performance in the formative and summative assessments was a predictor of their results in the final examination. Overall, nearly 90% of the cohort passed the unit with an even distribution of marks.

Computing Skills and Knowledge - Survey

To assess the impact of the unit on the development of IT knowledge and skills in students, a survey, with the same set of questions, was administered to students at the beginning of the semester and again upon completion of the unit; the surveys were coded with student identifiers to facilitate the analysis of improvement. The survey included a set of 20 quantitative questions to which students provided responses using a 5-point Likert scale.

IT tools and services – Types and frequency of usage

The first 10 questions related to the frequency with which students used various technologies and tools; the responses to these questions ranged from ‘several times a day’ (5 on the scale) through ‘once a day’ (4), ‘several times a week’ (3), ‘once a week’ (2), to ‘occasionally or not at all’ (1).

Unsurprisingly, the most frequent use was related to email (Q2) and Internet searches(Q1); this was followed by Facebook, or similar services, (Q8), and word processing (Q3); as illustrated by the results of the pre- and post-intervention surveys, included in Figure 4, the pattern of usage has not changed following the students’ participation in the unit.

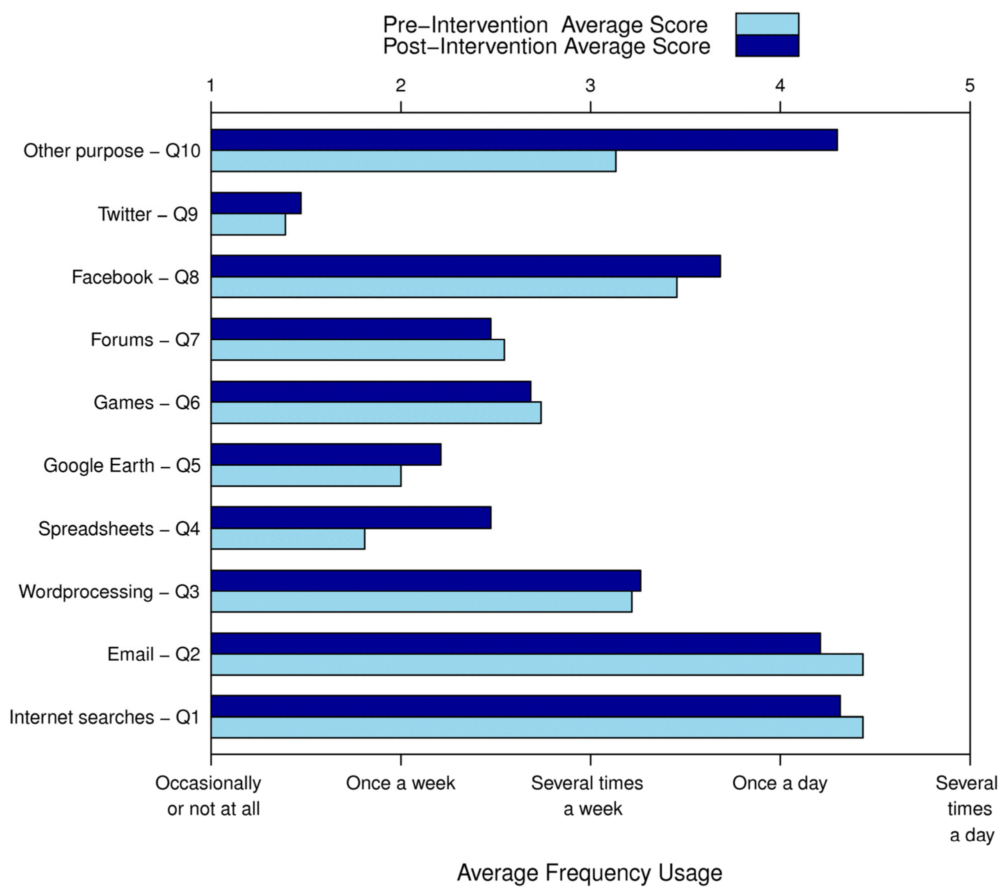

Figure 4: Frequency of usage of IT tools and services.

A noticable change in usage frequency, but not patterns, related to question Q10, “other purposes”; students identified programming, watching videos, and using PhotoShop and net-banking among the purposes. The initially surveyed average frequency of use of ‘once a week’ has increased to between ‘several times a week’ and ‘once a day’ in the post-intervention survey however, the change was not statistically significant (Wilcoxon test; p=0.581).

IT Knowledge and Skills – Self-efficacy

The latter 10 questions related to student self-efficacy with respect to IT skills and knowledge; the responses to these questions ranged from ‘expert’ (5 on the scale), through ‘better than average’ (4), ‘average’ (3), ‘beginner’ (2), to ‘no experience’ (1). In addition, the post-intervention survey included two open-ended questions related to the curricular and pedagogical approach employed in the delivery of the unit.

Predictably, students perceived their level of skill as ‘better than average’ with respect to the internet and email (Q11 & Q12), slightly less than that in word processing (Q13), and about ‘average’ in working with spreadsheets (Q14). As illustrated by the results of the pre- and post-intervention surveys, included in Figure 5, the level of self-efficacy related to those questions has changed minimally following the students’ participation in the unit.

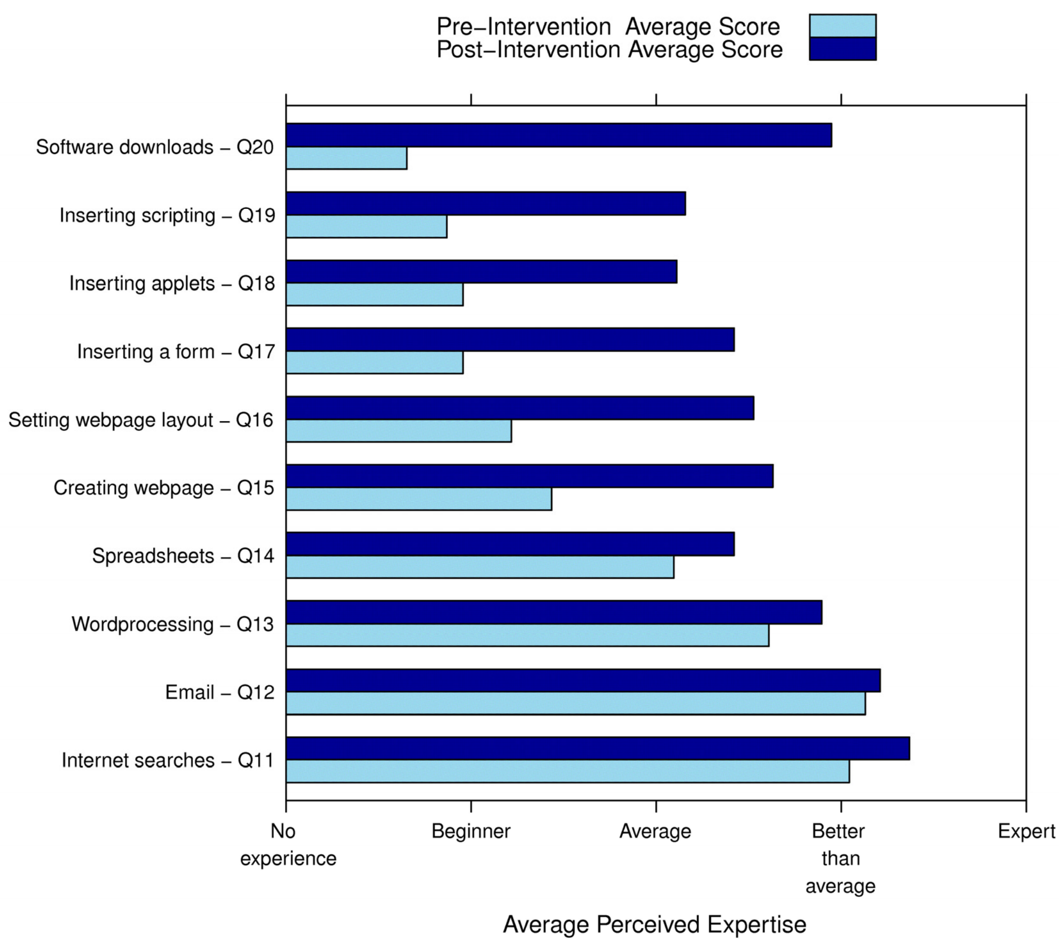

Figure 5: Perceived expertise of IT knowledge and skills.

A significant change was recorded with respect to perceived improvement in Web page design and authoring skills. Originally students assessed themselves as ‘beginners’ with respect to those skills. Their self-assessed level of expertise has risen to between ‘average’ and ‘better than average’ post intervention; importantly, the change was statistically significant. Students significantly improved their level of expertise in creating a Web page (Q15, Wilcoxon test; $p=0.002$); setting the layout of a Web page (Q16, Wilcoxon test; $p=0.001$); adding a form to a Web page (Q17, Wilcoxon test; $p<0.001$); inserting an applet to a Web page (Q18, Wilcoxon test; $p=0.003$); inserting scripting (Q19, Wilcoxon test; $p=0.001$); and, using the Internet for software downloads (Q20, Wilcoxon test; $p<0.001$).

In response to an open-ended question, student assessed as helpful the use of discipline-specific examples in laboratory classes. They stated that the examples improved their understanding of the underlying theory and made learning more interesting and easier. Several students found the approach particularly helpful with respect to creating Web pages for presenting content.

Commenting on the opportunity to choose a topic related to their specialization for the Web site development assignment, the students responded that it was helpful in a number of ways. It helped them realize that “there was more” to their Degree than previously anticipated and made the task relevant, easier, interesting, and fun:

> *“At least I know about what I am creating.”*
>
> *“It made finding content for the web page a lot easier.”*
>
> *“It was better to pick our own topics, as it kept it interesting.”*
>
> *“Involved a degree of interest since it related to my degree specialization.”*
>
> *“It was rather fun to be able to work in our own domain.”*

The freedom to select a specialization-related topic was also reported to have facilitated learning. According to the participating students, it was *“very helpful, it was like studying at the same time”* and *“it gave a better way of learning a particular topic and was more interactive.”*

Conclusions

The incorporation of an IT unit in the first year of a Specialist Science Degree at Victoria University has provided an opportunity to address a growing need for the development of adequate IT skills in university students and, particularly, in science students. The development of such skills in students is a challenging task, especially in the context of a Degree where students enroll in the main specialization of their choice, but they all share a common first year.

The enabling IT unit that was developed in response to this challenge has drawn on the generic nature of IT skills and emulated the underpinning philosophy of the Degree by building learning experiences that combined common components (theory) and specialized ones (practical applications). Thus, the framework for the delivery of the IT unit further reinforced the universal character of the Science Degree and, at the same time, demonstrated the universal applicability of information technology skills.

The evaluation of the pilot offering of the unit confirmed the usefulness of the pedagogical approach adopted in the design and implementation of the unit. The participating students reported significant improvements in their levels of expertise related to IT knowledge and skills, particularly in the area of Web design and authoring. However, further work is needed to improve the soundness of the approach, extend its application to a wider IT curriculum, and develop specialization-specific practical tasks for a wider range of IT concepts and topics.

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Biographies

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