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ORIGINAL PAPER

# Sparking self-sustained learning: report on a design experiment to build technological fluency and bridge divides

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**Abstract** In this article we report assessment results from two studies in an ongoing design experiment intended to provide a single school system with a sequence of secondary school level (ages 14–18) computer technology courses. In our first study, we share data on students' learning as a function of the required introductory course and their pre-course history of technological experience. In order to go beyond traditional assessments of learning we assessed two aspects of students' "*learning ecologies*": their use of a variety of learning resources and the extent to which they share their knowledge about technology with others. In our second study we present patterns of course taking by male and female students who have almost completed their secondary schooling. In addition, we share case studies of students who elected to take more technology classes and leveraged their course experiences for internships, further education, and jobs. The quantitative and qualitative data are consistent with our hypothesis that students would become more technologically fluent and that their *learning ecologies* would diversify as a result of their project-based experiences.

**Keywords** Equity · Design experiment · Learning resources technological fluency · Professional development · Computer science

## Introduction

Advances in communication and information technologies are rapidly changing processes of knowledge creation, economic systems, and human interaction. From

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an educational perspective, these changes have raised two critical challenges: (1) How to prepare students for a world that is technologically advanced and subject to constant change and (2) How to recruit the next generation of computer scientists, inventors, and technology specialists.

Each of these challenges raises fundamental equity issues. There is a need to prepare all students to capitalize on new technologies and a critical need to increase the diversity of the membership of professions that contribute the most to innovation. Currently these fields suffer from an underrepresentation of women and minorities. Differential participation in courses starts early, even when there are school-based learning opportunities available to all (AAUW, 2000; Barron, 2004; Bente, 1992; Dickhauser, 2003; Staberg, 1996). The differences remain if one looks at college data, and grow with each level of advancement (Camp, 1997; CCST, 2002; Charles & Bradley, 2005; Colley, 1998; Hutchinson & Weaver, 2004; Selby, 1997).

Lack of participation by underrepresented groups results in the loss of critical design resources that could otherwise be provided by more varied perspectives. Research suggests that design processes benefit when developers come from a broad range of backgrounds, concerns, and life experiences (Pinkard, 2000). Design solutions benefit from empathy with users' needs, and given the huge range of potential applications and consequences of technological design we should be seeking to recruit the broadest possible set of human innovators. More generally, lack of participation and interest in technological fields is a critical problem due to the loss of significant talent that could contribute productively to the workforce (CPST, 2001, 2004, 2005; ENWISE, 2004).

In the United States and other countries, opportunities to learn about computing technologies in school vary widely. Research on the use of computing in schools shows that only a small proportion of teachers use computers in ways that might enhance various aspects of technological fluency and engage sustained interest in technological subjects (Becker & Riel, 2000). Opportunities for students to take courses that focus specifically on programming, technology, or design are quite rare. In a national probability sample of American high schools, Becker found that only 10% of computing classes involved computer science or programming. Only 4% focused on multimedia or design (Becker, 2001). Further, the percentage varied as a function of socio-economic status (social and economic circumstances used to denote a quartile ranking of a population, SES). While the proportion of schools in the top three quartiles of SES offering computer science classes ranged from 10% to 14%, only 5% of schools in the bottom quartile offered such courses.

This variability is not surprising given that state-level standards for computer technology education have not been defined. Although ISTE's National Educational Technology Standards (NETS, see http://www.cnets.iste.org) has defined standards for technology use in relation to subject areas, it does not address the content of specific fields such as computer science and multimedia. The Association of Computing Machinery has published a report that articulates the need to increase public understanding of computer science as an academic and professional field (ACM, 2003). They stress the necessity of distinguishing computer science from areas such as information technology, mathematics, and other sciences and propose a K-12 curriculum that will begin to address this need.

Reports on secondary school computer technology curricula outline a number of other barriers preventing more and better offerings (Ben-Ari, 1998; Roberts, 2000; Schollmeyer, 1996; Stephenson, 2000), including lack of expertise, minimal budgets, lack of dedicated departments, and lack of knowledge by administrators. In the 1990s, there were so many job opportunities for programming talent that even universities had a hard time recruiting and retaining qualified instructors.

The constraints outlined in these reports offer a rather pessimistic view of the potential for schools to improve their offerings in computer technology or other fluency building courses, such as science-technology-society courses. However, there are good reasons to challenge this view. Reports of what is currently practiced do not reveal the potential to support the development of teachers who are more hesitant to innovate and are isolated. Work on educational reform in subject areas such as mathematics suggests that there are important systemic features of the organization of the school or subject area department that are related to innovation in practice (Cohen & Ball, 1999). For example, research that contrasts more and less successful mathematics departments suggests that certain characteristics tend to co-occur to produce success for students who do not traditionally reach high levels of achievement. These include collective moral commitment to student achievement, common rigorous curriculum, use of innovative practices, and appropriation of technology to enhance practice (Gutierrez, 1996). Even teachers who have not majored in computer science might be able to facilitate activities that provide fluency-building experiences and serve to engage the interest of students in continued learning. Having highly trained teachers already experts in the subject matter would be easier, but it is important to examine how we can support the teaching talent that is available.

Recent scholarship on the teaching profession provides new images of the teacher as learner and new models of expertise development (Hawley & Valli, 1999). For example, traditional teacher preparation approaches are designed to take place during a limited time period followed by periodic refreshers. New models suggest that like in other professions, developing one's expertise is a continual process that benefits from ongoing opportunities to learn and reflect on practice with colleagues and other professionals in both informal and structured contexts.

In this article we report on a university–school partnership designed to overcome these challenges by creating a series of technology and computer science courses for the secondary school level (ages 14–18) and opportunities for teachers to learn the subject matter. Though the courses focus primarily on computing technology as opposed to the more engineering-focused field of Design and Technology, we believe that the underlying concepts and pedagogy of the courses are relevant to this community as are the model of professional development and approach to understanding student learning. Understanding fundamental concepts, design processes, problem solving, and communication are key elements in each of our courses, which mirror many of the ideas behind Design and Technology curricula. Our goal was to create learning opportunities for students that would promote knowledge development and spark the interest of male and female students in computing fields. The research effort is guided by a learning ecologies framework that assumes that learning is a dynamic process that can be distributed across the contexts of home, school, community, and Internet resources (Barron, 2004; in press). A working assumption of this framework is that once interest is sparked, learners will seek out new learning resources and create learning opportunities for themselves through pursuing additional coursework, finding text-based or interactive learning materials, developing relationships with other people who share interest, and defining new informal activities that require continued learning. This kind of self-initiated learning is a particularly important context for the development of students' identities as competent and generative users of technologies. We share two studies that test these ideas. Study I reports on changes in student knowledge, use of learning resources, and knowledge sharing as a function of participation in a required course that introduced students to the field of computers and technology. In addition, the role of prior experience and gender in learning are examined. Study II examines patterns of course taking by male and female students who have had opportunities to take multiple electives and contrasts the confidence, interest, and valuing of computing knowledge for different course taking profiles. In addition, case portraits of two students who took several of the courses are provided.

This project is an international collaboration as well as a university–school partnership. The courses are implemented in the country of Bermuda. The project came about when government and business leaders in this small island country undergoing dramatic economic reorganization focused their attention on better preparing Bermudian students to enter both college and the workforce. The national economy relies heavily on international businesses, which experience a favorable tax climate in Bermuda. From a business perspective, better preparation of young people was especially critical if firms hoped to rely on local talent rather than continual recruitment of off-island workers. The government was also concerned about longstanding racial disparities in access to high paying jobs offered by these firms and access to high-level executive positions more generally. According to the 2000 census (Bermuda Census Office, 2001), 58% of the island's population is Black Bermudian. Though Black Bermudians represent the island majority, they have historically been underrepresented in the more lucrative fields of employment on the island. Black Bermudians are overrepresented in the trade sectors, holding 67% of positions, and underrepresented in international businesses, holding 30% of the positions (Commission for Unity and Racial Equality, 2002). This set of concerns led the Bermudian leadership to recruit university partners to help develop an approach to meeting this need by better serving both male and female students in the government-funded secondary schools whose population is 81% black. A shared concern about issues of equity with respect to technology coupled with a conviction that the design of productive learning environments for computing technology was possible led to the current research and development project. Below we summarize the research literature on equity issues and computing focusing on what is known about the role of prior experiences and engagement in course taking.

## Equity and the need for a developmental perspective

Recent research on the participation of women in the computing sciences has indicated that rather than making consistent strides with respect to young women participating, we have seen decreases. Tracy Camp's (1997) study of trends of degrees awarded in computer science from 1980 to 1997 presents two significant patterns of the percentage of women in the field. The first is a drop at each level of the computer science "pipeline," from high school through graduate school. In 1994, women accounted for 50% of the high school classes, 28.4% of the undergraduate degrees, and 15.4% of the PhDs. The second trend is an almost yearly decline at the undergraduate level, from 37.1% in 1983 to 28.4% in 1994. This decline at the undergraduate level is critical, as it suggests that the already declining percentages through the pipeline will continue to shrink. In addition, despite the relatively equal numbers of young women and men enrolled in classes at the secondary school level (Camp, 1997), only 17% of the students taking the 1999 computer science AP exam were female (AAUW, 2000). The statistics for minority males and females paint a similarly stark picture. Specifically, only 5% of test takers were African American and 5% were Hispanic (AAUW, 2000). This problem is not unique to the United States. Though there are exceptions, women are underrepresented in computing and technology fields in most countries throughout the world for which data is available (Charles & Bradley, 2005; ENWISE, 2004).

These patterns call for a developmental analysis that investigates links in participation across time and contexts. Research on issues of equity *post-college acceptance* suggests that childhood and adolescent experiences with computing play a critical role in students' choices, degree of confidence, and their persistence once accepted into a computing-intensive college major such as computer science (Kersteen, Linn, Clancy, & Hardyck, 1998; Margolis & Fischer, 2002; Schofield, 1995). Many of these processes were revealed in a longitudinal, comparative study of the experiences of male and female college students who declared computer science as a major (Margolis & Fischer, 2002). Interviews with students suggested that experiences in and out of class lead to feelings and thoughts about their perceptions of fit with the major. These assessments typically involved self-comparisons with a stereotyped vision of the ideal programming student along dimensions of passion, obsession, or focus. These self-assessments also involved comparisons of prior experience and knowledge in relation to peers. In the eyes of many of the female interviewees, their male counterparts had come in programming since birth and their knowledge base far exceeded their own. Many felt that they would never catch up. Interviews revealed that from early on, boys had more access to computing at home and more mentoring from parents. Family and peer-based experiences playing games was a significant pathway for a sense of competence. A lack of fit leads many students to switch majors and this happens more for young women. Young men may feel that though they are not a perfect fit with a stereotyped ideal computer science student, they can "pass." While these comparative processes were critical for the decisions of some female students, others persisted despite feeling challenged. These were students who came from non-US backgrounds and who either felt that they had little choice but to persist or came with a strong focus on effort and increasing competence rather than on perceived native ability.

Prior experience has also been explored in shorter-term studies of learning. Evidence of differential experience among males and females was found among students taking an introductory computer science course focused on the language Pascal. Males came into the course with more experience (Kersteen et al., 1998; Taylor & Mounfield, 1994). This knowledge for the most part was gained outside of school through hacking and unguided exploration. For males, the amount of prior experience predicted course grades. Females came in with little experience and experience did not predict course grades. Studies in countries around the world including Germany, Norway, Australia, Israel, and Canada suggest that males from primary school to pre-university have more access to and greater experience and confidence with computers and technology (Bannert & Arbinger, 1996; Chambers & Clarke, 1987; Chan, Stafford, Klawe, & Chen, 2000; Nachmias, Mioduser, & Shemla, 2001; Tor, 1996). Male technology experience is often a result of informal learning opportunities outside of school (for example, with games), sometimes before even entering into formal technology coursework (Margolis & Fischer, 2002; Nelson, Weise, & Cooper, 1991). Early experiences during the primary and secondary school years may be critical stepping-stones for later choices and comfort levels.

## A learning ecologies framework

As the above review suggests, learning about technology often takes place outside of school. In the Bermuda research and in other studies based in the United States (Barron, 2004), we are working to understand learning across life spaces of home, school, community and through distributed resources offered by the Internet (see Fig. 1). This conceptualization of learning broadens the unit of analysis to include the total set of contexts, comprised of configurations of activities, material resources, and relationships found in physical or virtual spaces that provide opportunities for learning (Barron, 2004). This learning ecology perspective highlights for study the emergence of interest and competence and the dynamics of how learning proceeds once interest is sparked. This framework is an extension of ecological theories of development (Brofenbrenner, 1979) and also draws on activity and sociocultural theories of development (Rogoff, 2003). With age, children have increasing opportunities to shape their own learning environments as they extend their peer networks, choose what to activities to engage in during leisure time, and exercise choice

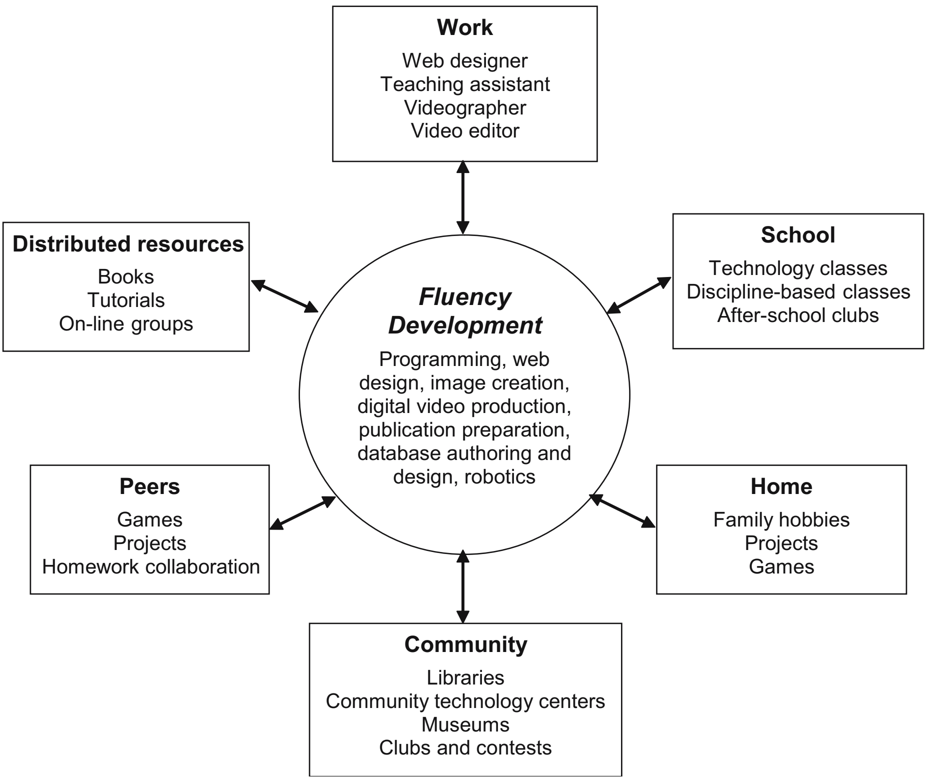


**Fig. 1** Contexts of fluency development

in the electives they pursue at school. Addressing issues of equity must begin with attempts to engage all students in high quality learning experiences. This design experiment can be viewed as an intervention designed to enrich all students' learning ecologies and to inspire further self-sustained learning on the part of those students who become interested. Our work towards this goal is described below.

## Project background

### *Interdisciplinary design work*

Since the fall of 1998, a group of faculty and students at Stanford University has been engaged in this multi-year design experiment to create, implement, and assess a new computing curriculum for the government funded secondary schools (ages 14–18) in Bermuda. The project is a collaborative effort of the Computer Science Department and the School of Education at Stanford, and Bermudian computing teachers. The Computer Science Department team provides the technical knowledge necessary to develop the curriculum content, the implementation skills needed to develop interactive computer-based teaching tools, and extensive experience in teaching computing concepts to college students with widely varying interests. The School of Education team provides expertise in the design and study of the learning environment—a process that involves developing pedagogical approaches, professional development, and measurement tools. The secondary school computing teachers provide observations and ideas based on their experiences in the classroom, adaptations of existing materials that better serve their individual students, and insights into their own learning through ongoing professional development sessions. By working together, the groups create a synergistic environment that has proven enormously valuable.

### *Design experimentation*

The design experiment we report here is based on the assumption that new teaching practices can be scaffolded in a learning-by-doing framework for integrating multiple kinds of resources for professional development and learning. This assumption is supported by research in other domains (e.g. see Barron et al., 1998) and emphasized in new perspectives that highlight the need for teaching to be viewed as a learning profession (Hawley & Valli, 1999) and supported by participation in ‘‘communities of practice.’’ By ‘‘design experiment’’ we refer to a cyclical process of course development based on theory and empirical research, classroom implementation, research of the impact of the new materials/practices on learning, and revision informed by this research (Brown, 1992). Long-term, university–school partnerships in which new practices, curriculum, and assessment strategies are treated as on-going design problems and approached jointly by researchers and teachers hold major promise for bridging theory–practice gaps (Barab, Hay, Barnett, & Keating, 2000). At the same time, research on school-based curriculum reform suggests the importance of transcending ‘‘hot-house’’ issues in local design experiment work (e.g. Fostering Communities of Learners (FCL); Center for Learning Technologies in Urban Schools (LeTUS), http://www.letus.org/) and work on how to achieve sustainable ‘‘design experiments’’ at a distance (Shavelson, Phillips, Towne, & Feuer, 2003).

### *Bermuda's educational reform efforts*

Bermuda is a self-governing British Overseas Territory. Since the mid-1980s, the country has been involved in a general education reform of its public school system to address significant inequities in educational opportunities. This reform has included curricula modification in all subject areas, elimination of entrance exams for secondary school, the addition of a fourth year to secondary school, mainstreaming of all special needs students into regular classrooms, and the introduction of middle schools (ages 11–14). Until the late 1990s, students in the government funded school system were tested at age 11 in order to determine their future schooling. Based on their scores, students were sent either to the one academic school or to one of several small general schools. The general schools did not offer many courses required for college, such as chemistry, physics or foreign languages. A higher proportion of girls attended the academic school. To address these issues, resources were combined to replace the general schools with one large senior school which opened in 1997, leaving two government funded secondary schools for the island student population. Formal student assessment was abandoned as a method for student placement between the two schools and both schools offer similar curricula including college preparatory courses.

The initial funding for this project-work came from the business world (International Education Collaborative Foundation (IECF)). The economy of Bermuda depends largely on tourism and international business. Part of the motivation for supporting computer technology courses in schools is to provide pathways for students to develop the kinds of competencies needed to go on to further education, or work in the companies present on the island. This issue has become more critical as tourism declines and international companies employ increasing proportions of the workforce. Without pursuing higher education and developing the ability to create new employment opportunities (as well as developing the ability to make informed decisions about the role of international business in the country) Bermudian young people will be increasingly limited in their choices for work.

### *School–university partnerships as a way to support innovation*

University–school partnerships organized around innovation in curricula coupled with studies of teaching and learning represent a model of collaboration that can both support ongoing professional development of teachers while also leading to the generation of empirical research designed to make theoretical progress on fundamental questions of learning (Grossman & Wineburg, 2000). In such partnerships each party has much to learn from the other and while "design experiments" that bring learning theory and educational interventions together in researcher–educator partnerships (e.g., Brown, 1992; Kelly & Lesh, 2000) can be time consuming and present a challenging research context, they also offer opportunities that cannot be replicated otherwise. This is particularly true in domains, such as technology, that are changing rapidly. The work presented here represents such an attempt and the story of its evolution is presented below.

### *Pedagogical design*

The content of our courses is consistent with ideas outlined in the recent National Research Council (NRC) report entitled *Being Fluent with Information Technology*

(NRC, 1999). In the United States, concerns about preparing youth for the future led the National Science Foundation (NSF) to ask the Computer Science and Telecommunications Board (CSTB) of the National Research Council to initiate a study that addressed the subject of *information technology literacy*. The study's rationale was the increasing ubiquity of information technology in daily life and the importance of beginning to define what everyone should know in order to empower all citizens to participate in this new era. Rather than use the term 'literacy' the authors of the report opted for the label 'fluency':

> While no term is perfect, the term fluency captures best for the committee connotations of the ability to reformulate knowledge, express oneself creatively and appropriately, and to produce and generate information (rather than simply comprehend it). It entails a process of lifelong learning in which individuals continually apply what they know to adapt to change and acquire more knowledge to be more effective at applying technology to their work and personal lives.

The standards for technological fluency expressed in the NRC report share important characteristics with standards that have been defined for science (NRC, 1996) and mathematics (NCTM, 1989). They each articulate the importance of integrating knowledge with the ability to engage in the forms of collaboration, problem solving, and discourse that are characteristic of participation in the discipline. These learning goals require educators to design classroom-based experiences that differ fundamentally from traditional pedagogical approaches that emphasize lecture, discrete lessons, and factual recall (Bransford, Brown, & Cocking, 1999).

In our work we meet these needs by organizing our curriculum around project-based learning opportunities that provide students with opportunities to learn content in the context of creating meaningful artifacts. Our design was guided by earlier work on project-based instruction and follows the design principles articulated by Barron et al. (1998). These include:

1. Defining learning-appropriate goals that lead to deep understanding
2. Developing social structures that promote participation and sense of agency
3. Ensuring multiple opportunities for formative self-assessment and revision
4. Providing scaffolding such as teaching tools, and beginning with problem-based learning activities before initiating projects

These principles were generative for our initial work, though the specific content has continued to emerge in the context of collaborative work with teachers. Building on our approach to project-based instruction, the curriculum strives to help students achieve self-perpetuating technological fluency by providing them with a set of fundamental tools with which to understand technology, from both a practical and social perspective.

### *Required and elective computer technology courses*

Five semester-long modular courses were designed for secondary school students: a required *Introduction to Computing*, two programming electives: *Introduction to Programming* (CS1) and a more advanced programming elective *Intermediate Programming* (CS2), and two multimedia design electives: *Visual Design* (MM1) and *Interaction Design* (MM2). Though the required *Introduction to Computing* and the programming electives focus primarily on computer technology, themes are designed to address universal issues of design and technology. The curricula strive to help students achieve self-perpetuating fluency by providing them with a set of fundamental tools with which to understand technology from both a practical and social perspective. *Introduction to Computing* includes a range of topics designed to build a foundation of general understanding in the area of technology. Students create timelines of computer history that identify themes in technology evolution including size, power, and connectivity. Basic systems and networks are explored, grounding students' use of computers in how they work. Students research and debate issues in the ethics of technology such as computer crime, intellectual property, and censorship. The major course project is the collaborative development of a website, including content generation, graphic and navigation design, and implementation using HTML. The two programming electives address fundamental concepts in programming themes and topics in the future of technology, and explore societal and moral issues in computing and technology. The multimedia electives cover traditional design principles such as elements, typography, and color, considerations of human factors in the design of print and electronic work, and current technologies for graphic and interaction design. Students are encouraged to produce work for their local community and develop a public service announcement for teenage youth and a website for a local non-profit organization.

### *Model of professional development*

Our model of professional development is consistent with research into teacher learning and new paradigms of teaching as an ongoing intellectual pursuit, focusing not on the mastery of static content but rather on the construction of meaning within a collaborative environment (Putnam & Borko, 2000; Darling-Hammond, 1998). Researchers and teachers jointly design the professional development sessions. Collaborative activities based on student projects expand content expertise, while critical, reflective discussions around student work assess quality, standards, and student understanding, grounding the new knowledge in actual classroom instruction. The combination of new content with real-world experiences and specific teacher expertise facilitates teachers' construction of their own knowledge, practices, and ideas (Putnam & Borko, 2000). Our model can be illustrated through a description of a session focusing on our Web Design module from *Introduction to Computing*: As teachers work in teams to build a website from design through completion using a mini-version of the student module project, interrelated components are structured to guide their experience. New content, such as HTML, storyboarding, and the design process, is introduced through small lessons; pedagogical ideas surrounding project-based instruction and collaborative work are discussed; teachers design and use rubrics to assess their own, each others' and students' design work; and student and teacher insights from video interviews and teacher adaptations of course materials are used to promote reflection and further exploration of how the project and topic can work in the classroom. The explicit goal of these sessions is to familiarize the teachers with the course material and to help them construct a conceptual framework within which to understand it. Our implicit goal is to create a community of teachers who learn from each other and share emerging ideas and information.

From 1998 through 2003 we offered multiple contexts for teacher learning, including 1–3 day sessions throughout the academic year and 1–2 week sessions during the summer in addition to ongoing support via email, telephone, and video-conferencing. All computing teachers from the two secondary schools attended the sessions, ranging from 6 to 10 teachers.

## Study I

Study I examines the role of prior experience and gender in learning from the required course, *Introduction to Computing*. Four indices of learning were used in pre-course and post-course assessments. First, we used standard short answer and multiple-choice items to assess content knowledge. Second, we assessed experience with technologically mediated activities that were judged as likely to be fluency building. Third, we assessed their use of a variety of learning resources. Fourth, we assessed the extent to which students were teaching others what they know about technology. These latter two measures we considered as reflections of students' learning ecologies and developed them in order to test the hypothesis that even a semester-long course might have generative influences beyond those traditionally measured. In order to evaluate the extent to which the course was useful for students with a variety of backgrounds we compared learning of students with more and less prior experience with technology and report on how experience level related to access to computing tools at home.

### Methods

#### *Measures*

*Access, interest, and experience survey*. To assess students' interest in, access to, and prior experience with a variety of computing activities, a survey was created using both Likert-response items and open-ended questions. The questions were designed to tap into four main areas: (1) students' access to technology at home and school; (2) students' history of technology use across communicative, entertainment, learning, and fluency building activities; (3) students' use of formal and informal learning resources; and (4) students' motivation to learn about computing.

*Concept assessment*. To assess students' learning as a function of the required technology course, a 24-item short answer and multiple choice assessment instrument was developed based on the content of the *Introduction to Computing* curriculum, drawing items from each of the modules.

#### *Participants*

A total of 55 first-year secondary school students (age 14–15) completed at least one of the measures (Interest, Access, and Experience Survey or Concept Assessment) at pretest and post-test, 23 of whom were male. In the analyses reported below, we use as much data as we have available. Some of our analyses required data from both the Concept Assessment and the Access, Interest, and Experience Survey and so for these the sample is slightly smaller. A total of 44 students completed both measures at pre- and post-test.

### *Procedures*

Data were collected during the fall semesters of 2000 and 2001. Students were asked to complete the concept test and survey in separate sessions during their technology course class time. Research personnel read all items aloud to the students who were asked to keep pace with the class so that we could make sure they understood each question. Terms that were unfamiliar to students were defined.

## Results

The results of the first study are presented in four main sections. First, we describe our methods for assessing prior experience with technology and how experience related to home access to computing tools. Specifically, indices of prior experience with fluency-building activities and technology-mediated communication were devised to generate an *experience score* in order to compare more and less experienced students' scores on an assessment of knowledge related to the content. Second, we present findings on the relationship between prior experience and learning. Third, we report on efforts to measure two aspects of students learning ecologies and report on changes in these measures over time. Fourth, we report an analysis of changes in the number of technologically mediated activities students reported experiencing before and after the course.

### *Experience with fluency-building and communicative activity*

Fluency with information technology has been defined as a combination of skills, concepts, and intellectual capabilities that allow one to use technology to meet personal goals (NRC, 1999). Although there are many kinds of experiences that build fluency, we were interested in those that were more likely to involve some aspect of design, personal expression and/or require more advanced concepts related to computing. To ascertain students' history of experiences, they were asked to indicate the number of times they had participated in seven types of fluency-building activities (creating multimedia presentations, programming computers, making publications using desktop publishing applications, starting a discussion or newsgroup online, designing a website, publishing a website, and creating art). We were also interested in students' history of using computing tools to communicate with others and students were asked to report on their experience with ten communicative functions (reading email, sending email, finding information using the World Wide Web, accessing remote databases, participating in chat rooms, communicating with people in other countries, communicating with people in other schools, pen–pal exchanges, and social awareness exchanges).

To examine how students differed in their breadth of experience, we created an *experience score* based on the number of fluency-building and communicative experiences students had participated in at least once. Based on 55 students' responses, a median split was used to define a more and less experienced group. The median number of experiences was 5 out of a possible 17. A $t$-test confirmed that the average number of activities students had participated in differed significantly by level of experience, $t\ (2, 51) = -5.2, p<.001$ with more experienced students having a greater breadth of experiences ($M$=9.8, $SD$=2.8) than less experienced students ($M$=2.2, $SD$=1.78). A chi square analyses indicated no significant relationship between experience level and gender $\chi^2$=1.29 (df = 1, 56).

Students were also queried about their families' ownership of a computer and whether they had an email account. With respect to ownership, 59% of less experienced and 71% of more experienced students reported having a home computer. This difference was not significant $\chi^2$=.55 (df = 1, 39). With respect to having an email account, the more and less experienced students differed considerably. Only 24% of less experienced students had an email account compared to 68% of more experienced students. This difference was significant $\chi^2$=9.74 (df = 1, 50), $p$<.01.

*Relationship between experience and learning course-taught concepts*

A multivariate analysis of variance was used to examine the role of prior experiences and gender on learning. Relative experience and time of assessment were used as the independent and repeated measures factor respectively. The only significant effect was a main effect of time of test, $F$ (1, 42) = 131.33, $p$<.01 indicating that performance was greater at post-test ($M$=.71, $SD$=.15) than pretest ($M$=.41, $SD$=.18) for all students regardless of their history of experience prior to the course or their gender. Figure 2 shows the mean level of performance for more and less experienced students at pretest and post-test. The types of prior experiences we assessed were not related to performance at pretest. This is not surprising as the content of the course and test items focus on topics that are unlikely to be encountered informally, such as the history of computers. These data are consistent with the idea that courses can be designed that move all students towards greater fluency regardless of their history of experience or gender.

*Enrichment of students' learning ecologies*

Beyond gaining a better understanding of particular concepts and acquiring new skills, it has been argued that increasing students' general level of fluency with new technologies might have a self-perpetuating, transformative influence on students by

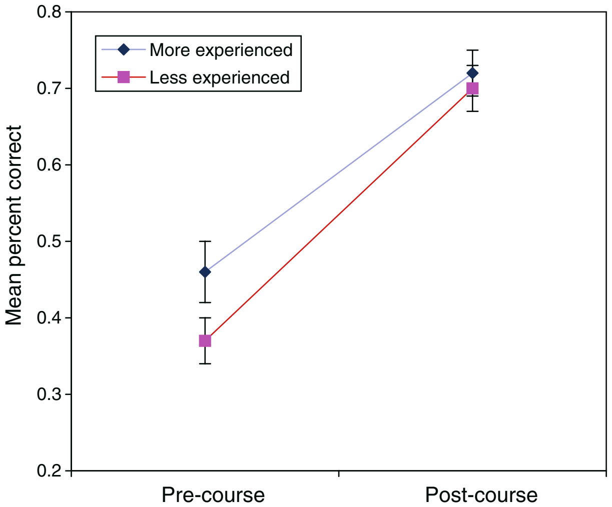


**Fig. 2** Concept assessment performance as a function of time and experience

changing the ways that individuals interact with one another and with the world (Barron, 2004; in press; Brown, 1999; Bransford & Schwartz, 1999). The measurement and analysis of two aspects of students' learning ecologies are reported below, as well as an analysis of changes in students' experience levels.

*Learning resources*. One concrete way that this kind of transformation might be observed is in changes in students' use of different kinds of learning resources. To assess the kinds of learning resources students utilize, they were asked to complete a checklist to indicate the different resources they used to learn about computing. Options included classes in school, classes out of school, friends, parents, books, television, tutorials, and practice. A multivariate analysis of variance was used to examine the hypothesis that the required *Introduction to Computing* course might increase the breadth of learning resources used by students to increase their knowledge of technology. Relative experience and time of assessment were used as the independent and repeated measures factor respectively. Figure 3 shows the average number of learning resources utilized for each cell of the design.

The main effect of time of test was significant, $F$ (1, 52) = 11.01, $p<.05$ indicating that there was an increase in the number of learning resources accessed from pretest to post-test for all students regardless of their history of experience prior to the course. The average number of sources of learning at pretest was 3.3 ($SD$=2.05) and 4.25 ($SD$=1.78) at post-test. The main effect of prior level of experience was also significant, $F$ (1, 52) = 5.7, $p<.02$. Students with greater experience reported significantly more sources of learning ($M$=4.28, $SE$=.29) than those with less experience ($M$=3.3, $SE$=.29). Figure 4 shows the percentage of students reporting that they utilize each learning source at pretest and post-test, collapsed across experience level.

*Teaching others*. Sharing knowledge with others is a key aspect of a student's learning ecology. Teaching others about technology provides an opportunity to refine one's own understanding as it is reformulated for someone else. Sharing

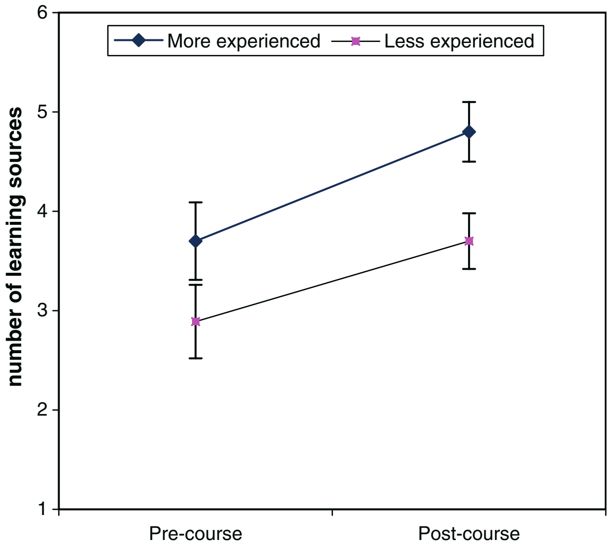


**Fig. 3** Average number of learning sources for more and less experienced students before and after the course

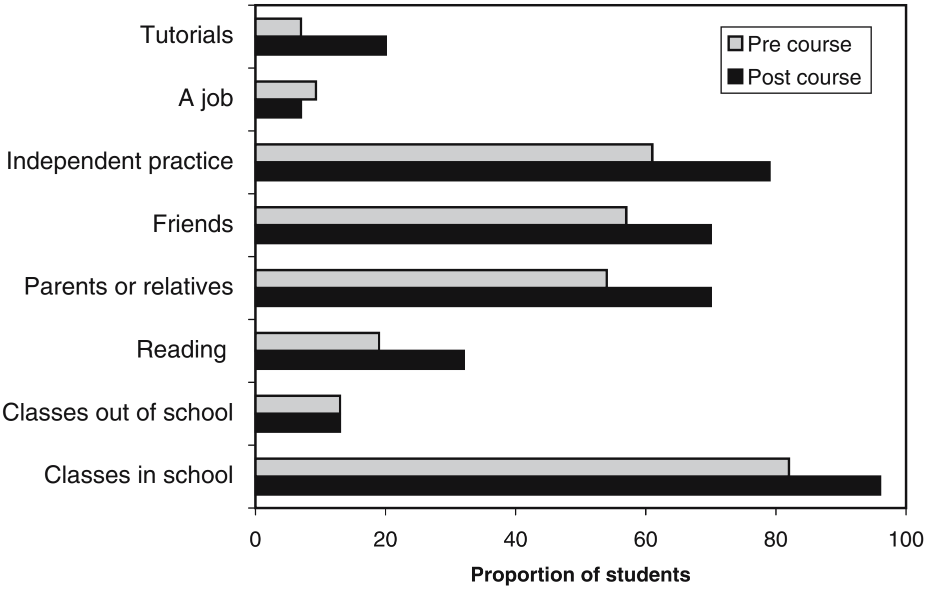


**Fig. 4** Proportion of students using different learning sources before and after course

knowledge with others can also be an expression of one's confidence and expertise. To assess the extent to which students were teachers as well as learners before and after the course we asked them to indicate if they were teaching anyone else what they knew and if so, who they were teaching. Options included parents, grandparents, sisters, brothers, friends, teachers, and co-workers. For purposes of this analysis, a *Family* category was created to encompass parents, grandparents, sisters, and brothers. A repeated measures analysis of variance was used to examine the hypothesis that the *Introduction to Computing* course might increase the likelihood that a student would share their knowledge with others. Four categories were tested separately: *Friends, Family, Co-workers*, and *Teachers*. Relative experience and time of assessment were used as the independent and repeated measures factor respectively. Table 1 shows the results of these analyses.

There was a significant effect of time for the category of *Friends*. Both more and less experienced students were more likely to report sharing knowledge with friends after the course. The proportion of students reporting knowledge sharing for each category is provided in Table 2. There was a significant effect of experience level for the category of *Family*. Students with greater experience at pretest were more likely to report teaching family members at both pretest and post-test than less experienced students. The effects of time and the interaction between time and experience were not significant. There were no effects for teaching co-workers or teachers. Very few students reported knowledge sharing in either of these categories.

These results are consistent with the hypothesis that the required course, *Introduction to Computing*, led to increases in the extent to which these students shared their knowledge with others, at least with friends. Why this was not true for families is an interesting question. Recall that less experienced students were not as likely to have an email account (and one might infer not as likely to have an Internet

**Table 1** Sharing knowledge before and after the course as a function of experience level

| Category | Source | df | *F* |
|---|---|---|---|
| Family | Time | 1 | 2.27 |
| | Experience | 1 | 7.56** |
| | Time × Experience | 1 | 0.25 |
| | Error | 52 | |
| Friends | Time | 1 | 5.21* |
| | Experience | 1 | 0.60 |
| | Time × Experience | 1 | 2.99 |
| | Error | 52 | |
| Teachers | Time | 1 | 0.31 |
| | Experience | 1 | 0.38 |
| | Time × Experience | 1 | 0.31 |
| | Error | 53 | |
| Coworkers | Time | 1 | 0.38 |
| | Experience | 1 | 1.44 |
| | Time × Experience | 1 | 3.11 |
| | Error | 52 | |

*Note*: *$p$<.05; **$p$<.01

**Table 2** Proportion of more and less experienced students teaching others at pre- and post-test

| Category | Experience level | Time | |
|---|---|---|---|
| | | Pretest | Posttest |
| Family | Less | 0.22 | 0.37 |
| | More | 0.55 | 0.63 |
| Friends | Less | 0.29 | 0.32 |
| | More | 0.29 | 0.52 |
| Teachers | Less | 0.00 | 0.04 |
| | More | 0.04 | 0.04 |
| Co-workers | Less | 0.04 | 0.04 |
| | More | 0.110 | 0.037 |

connection). It is possible that this limited the kinds of things that could be shared with families such as HTML programming or students' greater understanding of the Internet.

### *Growth in range of experiences*

To assess growth overall in the breadth of technologically mediated experiences, the numbers of activities students engaged in before and after the course were compared. A repeated measures analyses of variance was used to examine the role of prior experiences and the course on growth in experience. Relative experience and time of assessment were used as the independent and repeated measures factor respectively. Figure 5 shows the mean number of experiences reported for each cell of the design. There was a significant main effect of time of test, $F$ (1, 47) = 19.11, $p$<.001 indicating a greater number of activities experienced at post-test than pretest. There was also a significant effect of experience, $F$ (1, 47) = 82.64, $p$<.001, reflecting the greater number of activities the more experienced group had experienced. Finally, there was an interaction between time and experience level, $F$ (1, 47) = 12.14, $p$<.01. As reflected in Fig. 5, less experienced students reported greater growth in

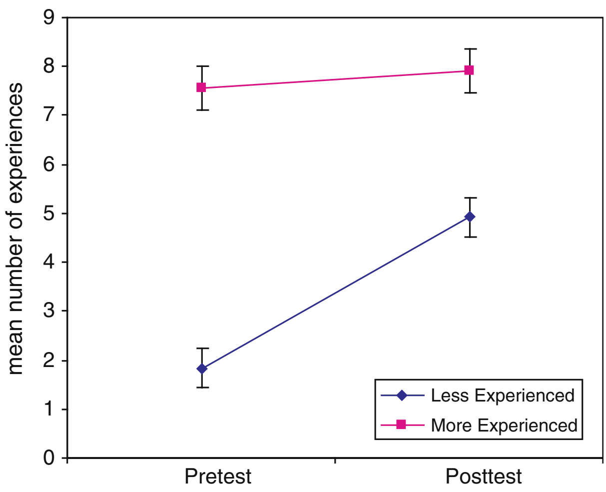


**Fig. 5** Number of technologically mediated experiences before and after course

their overall experience with computing technology over the time of the course than more experienced students. Despite this, they did not catch up to the more experienced students who, on average, reported experience with about three more technology-mediated activities than the less experienced students.

Table 3 provides the proportion of more and less experienced students who had ever participated in each of the technologically-mediated activities at pretest and post-test. This table reveals that for some activities, such as designing websites, the gap between more and less experienced students was virtually closed after the

**Table 3** Percentage of students who have experienced specific activities before and after the course

| | Less experienced (%) | | More experienced (%) | |
|---|---|---|---|---|
| | Pretest | Posttest | Pretest | Posttest |
| *Communication items* | | | | |
| Read e-mail | 14 | 55 | 89 | 89 |
| Send e-mail | 14 | 52 | 96 | 85 |
| Find information using WWW | 36 | 83 | 85 | 96 |
| Access remote database | 0 | 17 | 48 | 40 |
| Look at newsgroups | 11 | 32 | 61 | 56 |
| Participate in chat rooms | 25 | 41 | 78 | 74 |
| Communicate with people in other countries | 18 | 34 | 81 | 70 |
| Communicate with other schools | 14 | 24 | 61 | 63 |
| Pen pal exchanges | 0 | 14 | 37 | 33 |
| Social awareness exchanges | 0 | 30 | 33 | 18 |
| *Fluency-building items* | | | | |
| Created a mutimedia presentation | 15 | 45 | 37 | 78 |
| Programmed a computer to complete a task | 11 | 10 | 59 | 54 |
| Made a publication using a desktop publishing program | 11 | 21 | 44 | 63 |
| Started a newsgroup or discussion group on the internet | 0 | 14 | 22 | 15 |
| Designed a web site | 19 | 93 | 44 | 96 |
| Published a website on the internet | 11 | 25 | 30 | 18 |
| Created a piece of art | 35 | 62 | 85 | 70 |

course. Other activities, those that were not targeted in our curriculum in the introductory course, continued to show a gap between more and less experienced students.

### Summary

Both male and female students showed significant improvement in their understanding of the concepts taught in *Introduction to Computing*. Differences in prior experiences were not related to learning outcomes. Beyond finding improvements on an assessment of near-term learning, significant changes were observed in the breadth of learning resources that students utilized. At the same time, the findings indicated that students who have access to a broader set of learning resources also have a greater range of experience. This relationship between access to learning resources and breadth of experience has also been found in a technology-rich population where there is substantial access to computers at home and school (Barron, 2004) suggesting that there is much to be understood about how learning resources are distributed and accessed. Both more and less experienced students were more likely to share their technical knowledge with friends after the course. In addition, both more and less experienced students increased their breadth of fluency building experience. In study II we provide data on course taking patterns and share qualitative information about the dynamics of learning and the growth of students' learning ecologies.

## Study II

Study I focused on learning in the near term following completion of a single course during their first year of secondary school. In study II, we collected data from students who were in the third or fourth year of secondary school (ages 16–18) and thus had the option of taking additional elective courses in programming or design. This data gives us a chance to evaluate whether we see differences in course taking by males and females when the choice for participation is up to them. Profiles of students were developed based on the number of courses they had taken thus far. Using both gender and course taking history as independent variables we looked at their association with confidence, interest, and valuing of computing knowledge. Finally, we use interview data to present examples of how students who chose to take several computing classes used their course-based knowledge to create new out-of-school learning opportunities.

### Methods

#### *Measures*

*Access, interest, and experience survey*. To assess students' interest, access, and prior experience with a variety of computing activities, the survey described for study I was administered.

*Interview*. To gain a richer picture of students' experiences with technology as a result of the courses, a semi-formal interview was developed around students' attitudes about technology and computing, experiences in and out of school, course-taking decision-making processes, and plans for the future.

### *Participants*

A total of 98 third and fourth year secondary school students participated by taking the survey of Interest, Access and Experience. Fifty-five of the students were male and 43 were female. Out of this group, 38 students were interviewed. The sample consisted of all students who were currently taking one of the elective courses at the time of data collection and a smaller group of students ($n$ = 13) who had chosen not to take any of the computing electives. These students were recruited from other subject area classes or were advisees of the computing teachers.

### *Procedures*

Data was collected during the spring semester of 2003 over a period of two weeks. Two researchers administered the surveys in class, letting students work through the questions at their own pace. These same researchers conducted individual 30- to 40-minute interviews with students in private rooms during class time.

## Results

### *Course taking profiles*

No differences were found in the total number of computing and design courses taken between males ($M$ = 3.02, $SD$ = 1.13) and females ($M$ = 2.65, $SD$ = .99). These means include the first required course. It is important to note that this is not a random sample of all students from the Bermuda government secondary schools but rather a sample that is heavily weighted towards students who had chosen to take at least one elective computing course from the sequence that was offered. In fact, overall, 19.4% had taken one elective in addition to the first required course, 42% of the sample had taken two electives, 17.3% had taken three electives, and 7% had taken all four electives. Within this sample of students we did find gender differences in the number of programming courses taken. The males in this sample on average took a significantly greater number of programming classes ($M$ = 1.15, $SD$ = .82) than females ($M$ = .77, $SD$ = .65), $t$ (1, 96) = 2.46, $p$<.02. Of the females in this sample, 54% had taken the first programming class only and 12% had taken both programming classes. Of the males, 31% had taken the first programming class and 42% had taken both programming classes. For the remainder of the analyses we compare male and female students who took differing numbers of electives. Three groups of students were formed: Students who took only the required course and no electives, students who took the required course and one or two electives, and students who took the required course and three to four electives. We were interested in whether gender would interact with the number of courses with respect to confidence, interest, or the value students placed in learning about computers.

### *Confidence, interest, and valuing of technological knowledge*

Students rated their agreement with statements reflecting their interest, confidence, and valuing of computing knowledge on a 5-point lickert scale (with 5 being agree strongly). Univariate analyses of variance were carried out, using gender and number of classes taken as the independent variables. Two items measured students' interest in computing. Responses were averaged to create an interest score. There was a significant main effect of number of classes on students' interest score, indicating that students who took a greater number of classes were more interested than students who took fewer classes, $F$ (2, 94) = 3.43, $p$<.05. There were no significant gender differences on this construct. Four items examined students' confidence in their ability to work with and learn about computers. The main effect of number of classes taken approached significance, $F$ (2, 94) = 2.6, $p$<.08. There was no effect of gender and course taking did not interact with gender. A further four items queried the value that students place on computing and learning about computers. There was a significant main effect of number of classes taken, $F$ (2, 94) = 3.8, $p$<.05.

These results indicate that course taking was correlated with interest, value, and to a lesser extent confidence for both male and female students. Table 4 shows the mean ratings on these variables. In all cases the pattern is the same with the highest ratings of confidence, interest, and valuing being provided by those students who took the greatest number of courses and the lowest ratings by those students who chose not to take any electives.

Below we provide portraits of male and female students who took more than one elective. We focus on the dynamics of their learning experiences within and outside of school.

## Case portraits

Survey data is useful for providing overall trends in how course taking relates to a number of outcomes. However, it is theoretically useful to understand how individuals make sense of the knowledge they are developing in these courses and how their growing competence is utilized for new activities and how it becomes integrated with their sense of self. The use of interviews as a data source is based on their utility in illustrating phenomena to the learning ecologies framework. These interviews allow us to create portraits of learning about technology in a genre that has been called technobiography in recent work (Henwood, Kennedy, & Miller, 2001). A life narrative approach allows us to chart a learning history in terms that go

**Table 4** Interest, confidence, and valuing of technical knowledge of students taking different numbers of courses

| Measure | Number of classes | Mean | Std. error |
|---|---|---|---|
| Valuing of computing knowledge | Required class only | 3.7 | .17 |
| | One or two electives | 4.2 | .07 |
| | Three or four electives | 4.3 | .14 |
| Confidence | Required class only | 3.8 | .19 |
| | One or two electives | 4.1 | .08 |
| | Three or four electives | 4.3 | .16 |
| Interest | Required class only | 3.7 | .25 |
| | One or two electives | 4.2 | .10 |
| | Three or four electives | 4.6 | .21 |

beyond metrics such as numbers of courses taken to include the meaning and attribution behind decision making and narratives of how the learning activities unfolded across time, resources, and historical context (Bruner, 1994; Elder, 1994; Linde, 1993). In addition, interviews can reveal processes that are missed through other methods and provide us with portraits that go some distance toward ''recovering the person'' in our theorizing about learning (Mishler, 1996). Other case study research (see Barron, in press) on students learning about and with technology revealed that once students become interested they often are active in creating new learning opportunities for themselves through developing new relationships with peers who are interested or adults who can help them learn. They also may seek out tutorials, books, or create new projects for themselves that allow them to build up their knowledge independently. Below, we provide examples of students who have taken several of the computing courses and used them to create new opportunities for learning and new ideas for their future. The names of the students, teachers, mentors and schools have been changed to maintain confidentiality.

*Case 1: Courses spark new career ideas, the pursuit of internships, and the securing of a job*

At the time of the interview, Monica was in her fourth year of secondary school. She had taken both programming courses and one of the multimedia courses. Her interest in computers was sparked at age 10 when she used the simple design application PrintShop at a friend's house. Over the next few years she pursued this interest and used PrintShop on her home computer to design invitations, flyers, and business cards. When she was 14 she took the required *Introduction to Computing* course and began making websites at home in her free time. Though she enjoyed working with computers, prior to taking the more advanced electives she was not familiar with programming and had not considered a career in technology: ''I wanted to be an accountant at first, and then [my computer teacher] kind of pulled me in. I was like, 'Programming ... Wow! This is great.' Then I noticed I could have a career in computers.''

In the first programming elective, she enjoyed programming problems that frustrated most of her friends, and was encouraged by her teacher and peers to continue on to the next course. She was frequently asked to help her peers and she enjoyed explaining the programming concepts in her own words. At home she helped her mother learn though she found it challenging. As she put it, ''I try to teach her but it's the small stuff like PrintShop. She takes a lot of patience.'' The second programming elective proved to be more challenging, and in fact caused her to have second thoughts about her career path: ''When I first took [CS2] it was okay, then it got harder and harder and I said, I was like, 'Whoa now, let me think about my career now'.'' However, with the help of teachers and a graduate student who was visiting from Stanford, she persisted:

> ''Wow, I have never been frustrated in any of my classes, but then [CS2] came along. I would print out my work, I would take my work home. You didn't have to, but I would take it home to fix that problem. You don't know how many times I did that...It's hard, but when you see your results – great. You see your work and it's nice. Everyone will come around to watch it.''

Monica often stayed after class during which time her computing teachers taught her additional concepts and showed her new applications.

During the summer before her final year of secondary school, Monica leveraged an assignment in a work experience class to contact local technology companies to set up a job shadowing experience. Through shadowing an independent consultant, she met people in technology departments around the island and got their business cards. Monica interviewed three of her new contacts about their work and used these connections to secure an internship in the technology department of a local insurance company, during which she learned how to create and deploy an online database. The company gave her manuals to learn from and she also had interactions with the company's programmer who showed her his database in addition to explaining concepts. These experiences were incredibly productive for her. She watched the ways that the programmers worked and observed the kinds of problems they were solving. She also learned that companies often hire outside consultants, a position that appealed to her because of the variety of projects.

Near the end of her final year of secondary school, her computer teacher told her about a job opening and suggested that she apply. Her mother encouraged her to continue calling the company until she received a definitive answer. Monica got the job and that summer worked to design and program a website.

When asked if she thought there was a stereotype of a computer scientist held by the average person she replied, ''probably they would say a male because there are a lot more men than women. That's why I told Mr. Crandle [the person she shadowed] 'Okay, well I'm going to be one so you watch out for me'.'' Though she sees computer science as a male-dominated world, she now sees herself as part of that world. She plans to go to the local community college for a year and continue working, and then go away to college in Canada to study computer graphics or software design. Beyond web design, Monica would like to know how to write software and design games and other online worlds.

The required *Introduction to Computing* course was an important trigger for the expansion of Monica's learning ecology. Her experiences highlight the interrelationships between the emergence of interest, the pursuit of new learning experiences, and the development of an imagined future self. When asked how she felt about programming at the end of the interview, she responded: ''I love it, that's me, that is what I am going to do.'' It's important to note that her confidence and affect did fluctuate across time, and her certainty particularly flagged when the material became more difficult in the second programming elective. However, she was able to persist with the support of her teachers and her case portrait reveals the importance of other people in sustaining engagement and continuing to diversify her learning ecology. For example, her teachers recognized her interest and she was given extra opportunities to learn after class and to help others learn in class. Her mother was also a critical source of encouragement and advice. Finally, her interest and competence gave her opportunities to expand her social network and make the acquaintance of several computer consultants who worked on the island. These contacts were made through her first job shadowing experience that was instigated by a non-computer related course called ''work experience'' and proved to be critically important in helping her gain a concrete vision of the kinds of activities local computer professionals engage in as well as learn more generally about approaches to work such as consulting. Monica clearly came in to the *Introduction to Computing* course with some interest in learning to use computers. However, her understanding of computing sciences was minimal. What she learned in the courses helped her to gain an internship and a job, furthering her learning opportunities.

*Case 2: Courses spark passion for programming, independent learning, and acceptance to a college program in electrical engineering*

At the time of the interview, Nelson was a third year student who had taken both of the programming electives and excelled in the classes. He had not yet taken any multimedia courses. Having never had a new computer, Nelson grew up tinkering with old machines to get them to run. At home, he was the computer expert. Although his mother had some experience with computers he tried to help her learn more. His father drove a water truck and though he used a great deal of mathematics, had no idea what to do with a computer. Unlike students who take the computer classes because they view them as a smart move for their future, Nelson's passion for the discipline seems to be the deciding factor. When asked why he continued to take programming classes, he replied that he "just had a love for the programming." His initial interest in computers stemmed from playing video games.

> "It was the games and I thought, I really enjoyed this [flight simulator game] and it was such an experience I thought I want to be a pilot, but then I realized I really actually I like more of the computer than the game. So as I grew I became more mature and realized what I really liked."

After taking the first programming elective (CS1) he found C++ tutorials online and learned some basics of the language building on his prior knowledge from the introductory language used in the CS1 course. He also developed an interest in tinkering with demo programs found online, trying to modify their code to get full versions of the programs to work. When he went on to the second programming elective (CS2) he found that he was familiar with some of the material.

> "I was looking for some programs like C++ on the Internet, I didn't really know that much about it but just I learned, got some programs that teach us the basics of programs. So when I got to the [CS2] classroom she was teaching us something and I said, 'Yeah, I know this'. Just from my own research I was like ahead of the class."

At the time of the interview, his plans for the future looked more toward training than toward an academic college, however, he was being encouraged by friends, family, and teachers to look at technology focused academic institutions like Georgia Tech and MIT. He had one more year of secondary school and planned to take a course in Multimedia, but he wanted to eventually go into Robotics design. He felt that he was prepared for further study in this area, be it technical or academic. When asked how he thought the courses would be valuable later he replied:

> "Basically you learn your foundation. You will probably learn it when you go into college, but I think that if I take these courses now, I will be flying through. If I take these courses now, when I get to college I'm going to be flying through, just flying through, and be able to comprehend and keep up with the teacher."

We are beginning a follow up study of students who have graduated from secondary school and Nelson responded to our request for a follow up interview with a report on his experiences at a technical design college in the United States where he is finishing up his second year:

> “Little did I know when I was taking some courses that I would return to some of the familiar material; but sure enough I did. In my second quarter, I took digital electronics. It required understanding of binary, hex, octal and other related material. In my third quarter, I took a microprocessor course. That course re-introduced me to how computers store data to memory and how the microprocessor worked. I’m currently in my fifth quarter and I’m taking a PLC course. It’s basically programming on an electronic level, somewhat similar. However, my technology (program) required that I take another technical elective. I ended up taking Intro to Programming. That introduced me to Q-BASIC. I’m finding that the very same concepts that I learned in my [secondary school programming] class are being applied to the Q-BASIC course. These range from simple flowcharts, to how to decompose a program and sub-routines. I’m still in this course though and have yet to see what it has in store for me though I am very grateful for the introduction to the similar material in the [Bermuda school] courses”.

Like Monica, Nelson’s experiences highlight the dynamic nature of interest development and learning. Informal experience playing games and learning to use music editing software were elaborated in school where he began to develop a broader and deeper sense of the field of computer science and where his love of programming was sparked. He spent discretionary time exploring the Internet looking for tutorials that might help him learn more about programming and this exploration helped prepare him for his courses. In school, teachers also recognized his growing expertise and he was asked to help his peers. In Nelson’s case, the courses offered in school deepened his knowledge and paved the way for him to be accepted into a program that will allow him to obtain a degree in electrical engineering.

## Discussion

Since the coining of the phrase “digital divide,” the discourse has rapidly shifted its focus from a concern about who has access to new information technologies to who will have the knowledge that will position them to design, create, invent, and use the technologies to enhance their personal lives and social worlds (Castells, 1996; New London Group, 1996; Reich, 2002). Although concerns about equity provide one argument for why we should be empowering all students to engage in technologically mediated design or the design of new technologies, another argument is that we need to engage a more diverse group of designers for the benefit of the broader society. Designs are often produced with respect to the perception of need. In this way, design involves empathetic processes. To the extent that we have designers who are homogenous with respect to life experiences we restrict the possibilities of how problems are defined and solutions formulated.

In this paper we shared our ongoing efforts to address issues of equity and diversify the population of those who might become involved in technical design related fields. Our design-experiment work consists of curriculum development, teacher professional development, and research. We provided data that examined the role of students’ prior technologically mediated experiences on learning from the introductory course. Our findings indicated that although in this sample students varied widely in their prior experiences, a lack of prior experience did not prevent them from benefiting from the projects and lessons in the course.

Beyond finding improvements on an assessment of near-term learning, significant changes were observed in the breadth of learning resources students utilized for both more and less experienced students. At the same time, the findings indicated that students who have access to a broader set of learning sources also have a greater range of experience. This relationship between access to learning resources and breadth of experience has also been found in a technology-rich population where there is substantial access to computers at home and school (Barron, 2004) suggesting that there is much to be understood about how learning resources are distributed and accessed. While the potentially transformative role of information technology for self-initiated and life long learning is often touted, studies that attempt to measure systemic kinds of outcomes are rare. The two measures described in this paper are novel and may offer useful metrics for other studies that look to understand the impacts of interventions on students' capacity to learn and teach in collaboration with new tools and social partners.

The case portraits offered of two students provide additional evidence of the dynamic nature of a learning ecology. Specifically, once interest is sparked, adolescents may generate their own kinds of further learning opportunities and their competence can be acknowledged by others. In the two cases shared in this paper we saw that the required introductory course was influential in their decisions to take the programming electives. Neither of these students had a sense of the field of computer science before the first course and were delighted when they came to understand what the activity of programming entailed. These portraits also illustrate the boundary crossing and bidirectional influence of interest driven learning. Monica saw class assignments in non-computer classes as an opportunity to interview computer professionals and shadow one of them at work. Her growing knowledge and competence was recognized by teachers and she obtained an internship while in secondary school and a job after graduation. Nelson sought out tutorials online and continued to develop his knowledge through technologically mediated hobbies while not in class and then later used this knowledge to understand course material. He pursued a four-year degree program and continues to report connections between earlier and later learning. Both of these students were fortunate in having adults that supported them. These adults played multiple roles such as asking them to help their peers learn, connecting them with adult mentors, alerting them to jobs, and encouraging their persistence.

## Future research

Several directions for future research seem promising. First, these data suggest the need to broaden our methods for assessing the generativeness of a learning environment. A learning ecologies model draws attention to between-context interdependencies and highlights how little we know about processes of interest development in relation to experience. It would be productive to understand more about how the creation of new and self-regulated activity contexts for learning can be triggered by formal (and informal) learning opportunities. To address these questions, research that utilizes a broader set of methodologies is needed. For example, assessments of students' social networks and longer term ethnographic studies would help us to better understand the development and dynamics of students' learning ecologies that span local and distributed resources and that are shaped by the self as well as by others. Each life context has unique features that afford different kinds of learning. The configuration of tools, activities, and relationships that students have access to at home, school, through the community, through peer groups, and through distributed resources might be the basis for a deeper assessment of students' learning ecologies than was carried out here. Metrics that gauged the diversity and quality of a learning ecology might also be useful for designers who want to design for secondary kinds of effects. It might even be possible to develop metrics of potential learning ecologies, based on the learning opportunities that are seeded throughout a community.

Second, a core element of this effort is our model of professional development yet we need more research on teacher learning. We began with the assumption that teacher learning could be supported in ways that would allow them to teach students substantive content despite being relatively novice with the material themselves. This assumption is in contrast to a deficit perspective with respect to teachers that suggests a lack of subject matter knowledge is an insurmountable barrier. For this work we developed a model of professional development characterized by a multi-year collaboration, sessions structured around the content and activities in the courses to be taught, and sharing of teacher innovations and adaptations to curriculum and assessment. These program characteristics are consistent with the recommendations of leaders in the field who argue that teaching must be considered a learning profession (Hawley & Valli, 1999).

Our observations and interviews suggest that as a result of the project, the teachers took on new roles such as teaching other teachers and several also sought out additional opportunities to develop their expertise. We have also found that as the teachers grew more experienced they made substantial revisions and adaptations to meet the needs of their students. These shifts suggest that the learning ecologies of teachers also expanded as a result of the project. Finally, over time, teachers needs have changed as they became confident with the course material. The group has become more differentiated with respect to their interests in learning additional material or revisiting course material. In response we have begun to adapt our model. Rather than designing sessions for all teachers around common material we conduct sessions where subgroups can focus on unique topics. These observations are positive though more documentation is needed. Due to the distance between the researchers and research site we were unable to carry out the kinds of observational research that would allow us to paint a richer portrait of teaching. This kind of work is crucial to provide more detailed portraits of changes in teaching. In the future we will be working with teachers to develop multimedia portraits of their teaching practice. These will be helpful in sharing their work with colleagues and will also provide us with a window into their conceptions of teaching. The use of video-cases of teaching practice and learning processes can provide powerful contexts for group discussions of teaching and of students' intellectual and collaborative work (Lampert & Ball, 1998).

Third, with respect to research design, we did not employ experimental designs or control groups. Given our relatively modest budget this was not possible nor would it have met the desires and needs of the Bermudian school community. However, it might be useful to undertake such work in another context, assuming one could develop appropriately focused questions that might be addressed by such a design. In our future work, we will continue to address questions about how differential course experience might play a role in broader developmental outcomes. Our data on enrollment suggests that a bit more than one third of the students elect to go beyond the compulsory *Introduction to Computing* course to take the introductory programming elective (CS1), and still fewer go on to the intermediate class (CS2). While this is promising, we need continued longitudinal data to assess the role that these school-based experiences might play in students' learning trajectories as indicated by both formal course taking, college, and job attainment. We realize that their success in college or jobs will be dependent on a broader range of competencies than those they are acquiring in our courses. We are currently following a subgroup of graduates to see if their goals are realized and to gather their reflections on the benefits and constraints of their earlier experiences in secondary school.

Fourth, though examining positive student learning outcomes in detail is informative, it is equally important to assess the restriction of interest that may come about from particular learning experiences. Data on classroom processes in the domains of computer science and mathematics have revealed how some students may become disaffected, unmotivated, and lose interest in a subject matter (Boaler, 2000; Schofield, 1995; AAUW, 2000). A challenge for the field is to understand dynamic processes of motivation and how they are linked to perceptions of fit, types of experiences, and teaching–learning relationships. Toward this end, we will be continuing to carry out analyses of interviews from students who did not become highly engaged by the course material.

## Challenges

A challenge to this research raised by audiences for our work is whether our findings can be generalized to the United States or other countries. Bermuda is unique in many ways, particularly with respect to its geographical location, size, economy, and cultural history. It is a British territory under self-rule. Nearly 600 miles off the coast of South Carolina in the Atlantic Ocean, Bermuda is one of the most isolated island chains in the world, with a population of only 60,000 persons living on a total landmass of 20-odd square miles. Over the last 20 years, its economic base has shifted from tourism to international business, making its economy one of the strongest in the world, as well as making it an extremely expensive place to live. The relationship between government and business is unusual due to the fact that the businesses do not pay taxes to Bermuda. Despite the country's apparent prosperity, due to its isolation and small physical size, it offers few employment opportunities for unskilled labor. Corporate jobs are prized, but many are taken by non-Bermudians as companies claim that they cannot find Bermudians with the requisite skills. Government funded schools are populated mostly by Bermudians, whereas private schools are more diverse with respect to both ethnicity and nationality. Corporate employees often send their children to private schools rather than to government schools. All of these factors create a unique developmental context for students.

Despite these unique features, we believe that in many important respects our findings are generalizable. For example, many of the school constraints faced by government funded secondary schools are quite similar to those faced by high schools in the U.S. These include limited expertise of teachers with respect to computer technology subject matter, little time for professional development, shifting educational standards, and a lack of standardized curricula. The Bermudian secondary schools also are challenged by extreme diversity in student achievement.

All special needs students were mainstreamed in 1995 and as a result teachers must find creative ways to meet everyone's needs. Reports on the 2003 Terra Nova tests, standardized in the United States, indicated that on average second year Bermuda secondary school students scored in the 30th percentile in math and reading. This profile is like many of our more challenged schools in the United States.

The question of whether we can generalize the results of this research is also being addressed by other studies taking place in the United States. We have been studying processes of learning across contexts and how self-sustained learning relates to learning resources and the development of interest (Barron, 2004; in press). The results of this ongoing research program suggest that the Bermuda results in regard to learning processes are generalizable.

In closing, we believe that this model can be productively employed in other cultural locales such as the United States or other countries. Having teachers and university partners co-located would be likely to benefit the success of the collaboration. Although the justification for engaging students in science and technology education is often based on economic needs we believe that there are other arguments to be made. Computer technologies are rapidly changing processes of human interaction and the potential for learning. Regardless of what kind of work one engages in, understanding how to leverage and avoid the pitfalls of new computer technologies will be crucial. Our design experiment work suggests that, at least at an introductory level, it is possible to support teachers to engage students productively around fluency-building topics and projects that are relevant to the discipline of computer technology and design. Technologies can be used to many ends and vision and imagination for positive uses will depend on deeper understanding of the underlying systems, the ability to engage others as learning and creative partners, and open discussion about challenges and opportunities brought about by globalization. The data shared in this article on the dynamics and growth of students' learning ecologies calls for expanding the ways that we assess learning environments for their potential to nurture valued yet understudied competencies such as propensities for self-sustained learning, the ability to learn and create collaboratively, and knowledge sharing.

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