A Design Experiment to Build Technological Fluency and Bridge Divides

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Abstract: In this paper we report assessment results from an ongoing design experiment intended to provide a single school system with a sequence of high school level computer science courses. We share data on students' learning as a function of the first course and of their pre-course history of technological experience. In addition, 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. The quantitative data are consistent with our hypothesis that students would become more technologically fluent and their *learning ecologies* would develop as a result of their project-based experiences. To supplement the quantitative data we provide two case examples that illustrate the nature of these shifts.

Introduction

Since the coining of the phrase "digital divide," the discourse has rapidly shifted 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 (Reich, 2002; Castells, 1996; New London Group, 1996). In a dramatic portrayal of a possible consequence of this widening divide, Castells (1996) envisions a future in which people become members of one of two groups – the interacting or the interacted. The interacting will have the resources to choose, develop, and critique new technologies while the interacted will be passively subject to its influence, perhaps without awareness. This redefinition of the problem highlights the need to pay attention to what we might call *innovational equity*.

In the United States a related concern led the National Science Foundation 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. The result of the committee's work was a report entitled *Being Fluent with Information Technology* (NRC, 1999). 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, 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.

High school as an important developmental context for fluency development

While the intended scope of the report included everyone, in the end the committee focused on an already advantaged group as their target: college undergraduates. While this focus made sense given the scope of their task, the question of fluency has relevance when we think about high school students who may or may not yet be considering college or careers that involve technology. 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, 1998; Schofield, 1995; Margolis & Allan, 2000).

Early experience at the high school level that can serve to interest students in the discipline of computer science and provide opportunities for building a broader conceptual framework that can support new visions of possible careers and the educational trajectories that might take them there. Given the underrepresentation of young black and Hispanic men and of young women of all ethnic backgrounds, there is good reason to work to develop quality opportunities to learn about the disciplines that are involved in the innovative uses of computing technologies early on. As pointed out by Margolis & Fisher (2000), this imbalance is not simply a matter of equity but is urgent for maintaining the vitality and diversity of ideas in the field as well as for ensuring that those who are designing have a broad set of users in mind.

Not surprisingly, in the United States and other countries, opportunities to learn about computing technology 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 (Becker & Riel, 2001). However, opportunities to take courses that focus specifically on programming 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 SES level. While the proportion of schools in the top three quartiles of SES offering Computer Science classes ranged from 10-14%, only 5% of schools in the bottom quartile offered such courses.

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, et. al., 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, LeTUS) and work on how to achieve sustainable “design experiments” at a distance.

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 public senior schools 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 is leading the research effort and provides expertise that informs the design of the learning environment and model of professional development. Our research goals are to improve practice while also advancing theories of student and teacher learning. 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.

Bermuda’s Educational Reform Efforts

Bermuda is a self-governing British Colony. It has been involved in a general reform of the public school education system since the mid 1980s. This reform has included curriculum reform in all subject areas, the addition of a 4^{th} year, elimination of the 11plus entrance exams for secondary school, mainstreaming of all special needs students into regular classrooms and the introduction of middle schools. These reforms were designed to address significant inequities in educational opportunities. Prior to the opening of a new large school in 1997, students were tested at age 11 in order to determine their future schooling. Based on their scores, students were sent either to an academic public school or to a general public school. The general schools did not offer many courses required for college such as chemistry, physics or foreign languages. In addition, the testing resulted in the majority of boys being assigned to the general school while the majority of girls were sent to the academic school. At the present time there are only two public secondary schools and student assignment is not based on formal testing.

The initial funding for this project-work came from the business world (the International Educational Collaborative Foundation (IECF). The economy of Bermuda is based mainly on tourism and international business. Part of the motivation for supporting CS in the 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 be involved in making decisions about the role of international business in the country) a number of Bermudian young people will be increasingly limited in their choices for work. A gradual process of transfer of responsibility to the Ministry of Education has begun while at the same time other community partners have contributed funds to support the effort.

Pedagogical Design

The standards for technological fluency expressed in the NRC report share important characteristics with standards that have been defined for science and mathematics (NCTM, 1989; NRC 1996). 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 this need by organizing our curriculum around project-based learning opportunities that provide students with opportunities to learn content in the context of creating meaningful artifacts. The design was guided by earlier work on project-based instruction and follows the design principles articulated by Barron, et al. (1998). These included: (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; and (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 of each emerged (and is still emerging) in the context of the collaborative work with teachers. Building on our approach to project-based instruction, the curriculum strives 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.

As of fall 2001, we have completed two semester-long modular courses designed for students in the first two years of senior school: a required “Introduction to Computing” (Course A) and an elective “Introduction to Programming” (Course B) that builds on the foundation created by the earlier course. Course A includes a range of topics that provide background understanding and offer opportunities for students to construct their own meaning. Students build timelines of computer history that identify themes in the evolution of the computer, such as size, power, and connectivity. Basic computer systems and networks are explored, grounding students’ use of computers in how they work. The networks section includes uses of the Internet beyond “surfing the web.” Students research issues in computing ethics such as computer crime, intellectual property, and censorship, and hold an in-class small-group debate. The web design module introduces the basics of design and HTML. The major course project is the collaborative development of a web site, including content generation, graphic and navigation design, and implementation using HTML. The course offers students a broader perspective of computers and technology as opposed to focusing on specific computer applications. Course B focuses on more formal programming, including Karel the Robot to introduce fundamental concepts, interactive web design with JavaScript, and themes and topics in the future of computing. Our intent is not to have students reach expertise with a particular language such as C++ or Java, but rather to gain a familiarity with multiple languages to promote an understanding of introductory programming fundamentals. Course A was first offered in 1999-2000. As of January 2002, 1464 students had taken the course, an average of 488 students per year. Approximately 40% of these students elected to take Course B, which was added to the curriculum in 2000-01.

Overview of our research on learning and learning ecologies

In this report we focus on our attempts to develop assessments of student learning as a result of the introductory course in our three-course sequence. Because of our concern with evaluating the extent to which the course was useful for students with a variety of backgrounds we have explicitly developed measures of prior experience with technology. 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. In addition, in order to go beyond traditional assessments of learning we assessed two aspects of students' current "*learning ecology*". The term learning ecology has been used by a number of authors (e.g. Brown, 1999) and reflects the recognition that students participate in multiple social worlds using a variety of tools and social practices. For this research we operationalized and measured two aspects of students' learning ecologies: their use of a variety of learning resources and the extent to which they teach others about technology. School is one aspect of a student's learning ecology but informal learning contexts are created as students seek out opportunities to learn through practice, reading, tutorials, friends, parents and other social contacts. Similarly, with new technologies youth have novel opportunities to become local experts and even share their knowledge with less experienced adults. As teaching is a widely recognized path to learning we include it as a measure of one aspect of a students' learning ecology. Teaching others can also expand one's identity in a community as their expertise allows them to relate to others in new ways (Wenger, 1999). Teaching others might also be considered an indicator of fluency (Resnick, personal communication). We look at these two aspects of students' learning ecologies as outcome measures in order to test the hypothesis that even a 10-week course might have generative influences beyond those traditionally measured. The results below are based on a sample of 55 students drawn from the classes of three participating teachers.

Results

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 look at 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, starting a discussion or newsgroup on-line, designing a web site, publishing a web-site, 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 data bases, participating in chat rooms, communicating with people in other countries, communicating with people in other schools, pen-pal exchanges, and social awareness exchanges).

Differentiating students on the basis of experience

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. 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 chi square analyses indicated no significant relationship between experience level and gender. 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).

Relationship between experience and learning course-taught concepts

A 24 item-short answer and multiple choice assessment instrument was developed based on the content of the curriculum. Multivariate analyses of variance was used to examine the role of prior experiences and the course on learning. Relative experience and time of assessment were used as the independent and repeated measures factor respectively. Figure 1 shows the mean level of performance for each cell of the design. The only significant effect was a main effect of time of test, F (1, 42) = 137.31, p < .00 indicating that performance was greater at post-test (M=.71, SD =.15) than pre-test (M= .41, SD=.18) for all students regardless of their history of experience prior to the course. 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 computer science. These data are consistent with the idea that courses can be designed that move all students towards greater fluency regardless of their home access and history of experience.

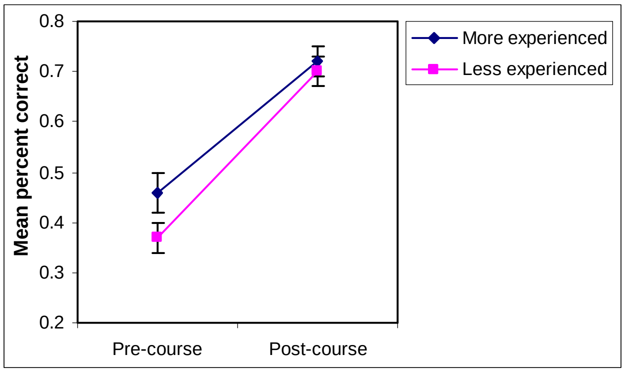

Figure 1. Concept assessment performance

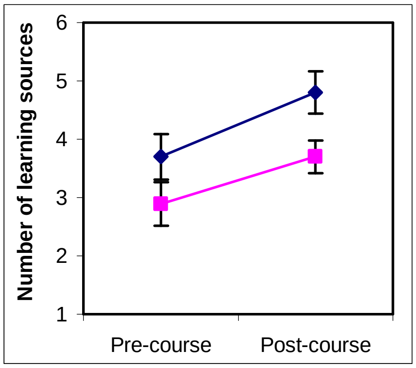

Figure 2. Average number of learning sources

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 changing the ways that individuals interact with one another and with the world (Brown, 1999; Bransford & Schwartz, 1999). 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 indicate from a list all the ways they believed they were learning about computing. Multivariate analyses of variance was used to examine the hypothesis that the 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 2 shows the average number of learning resources utilized for each cell of the design. The main effect of time of test was significant, $F(1, 52) = 11.01$, $p < .002$ indicating that there was an increase in the number of learning resources accessed from pre-test 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 3 shows the percentage of students reporting utilizing each learning source at pretest and posttest, collapsed across experience level.

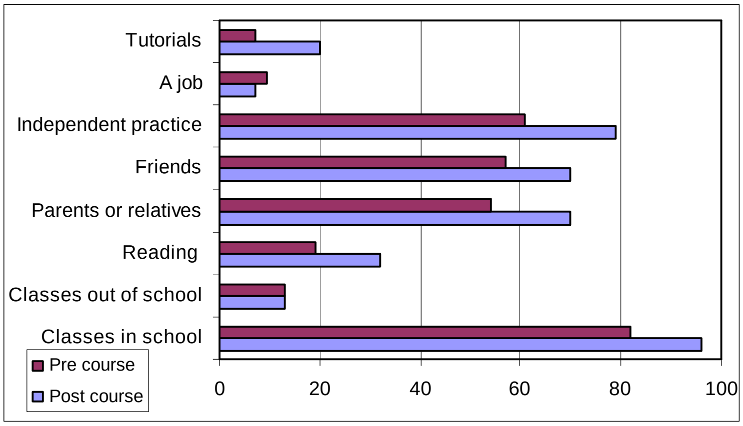

Figure 3. Proportion of students using different learning sources before and after course

A second aspect of a students' learning ecology is the people with whom they have the opportunity to share knowledge. Teaching others about technology provides an opportunity to refine one's own understanding as it is reformulated for someone else. Sharing 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.

Again, a multivariate analysis of variance was used to examine the hypothesis that the course might increase the breadth of the group with whom one shares knowledge. Relative experience and time of assessment were used as the independent and repeated measures factor respectively. The main effect of time of test was not significant. There was a main effect of experience level $\underline{F}$ (1, 53) = 9.6, $\underline{p} < .00$ indicating that both before and after the course more experienced students were sharing their knowledge with a broader group of people ($\underline{M}$=1.94, $\underline{SE}$=.23) than were less experienced students ($\underline{M}$=.95, $\underline{SE}$=.23). Figure 4 shows the proportion of students who report teaching anyone what they know, before and after the course. These techniques might allow one to generate more sophisticated models of a students' learning ecology than is possible here.

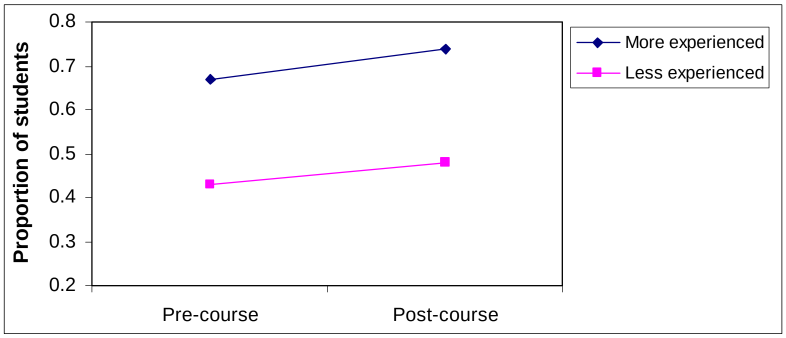

Figure 4. Proportion of students teaching others before and after course

Interviews to reveal developmental affordances of design projects

An interview protocol was developed to provide narrative data on students' learning that includes a series of questions in six areas. These interviews yield student talk that allow us to characterize the broad range of experiences that students have in the context of their work and to reveal important psychological and contextual influences on student motivation and learning. At this point our goal is not to assess the level of fluency that individuals develop, though these kind of data might be used to set benchmarks for different levels of expertise at a later point. For now the main goal is to establish the range of developmental affordances of these kinds of projects and to enrich our theories of the kinds of learning processes and outcomes we might expect. Here for the sake of brevity, but to focus deeply, we summarize what we learned from two students that illustrate ways that students' broadened their learning ecologies as a result of their experiences with the course. We begin with a student who had only taken the first course. Next we share some of the experiences of a student who has taken both the first and second course.

<u>Student 1, Jamal: "So far my web site career has really taken off…"</u>

Like many other students, Jamal began the first course with some computer experience but little conception of how programs were created – "When my mom bought me a laptop I didn't know anything about HTML, all I knew about the computer was it was something to type to…I did not know anything about the internet or nothing until I came here." When first introduced to HTML he wasn't sure that it would be worth the effort it took:

Interviewer: *So tell us about it, you said you really got excited.*

Jamal: Yeah, cause Mr. Handle was teaching us about computers and about HTML. At first I was like what is this cause I saw all the writing you have to do just for a web page, that's too much…but then when I found out what it was all about I said alright I can do this,…cause I'm a very creative person, it seemed good…after a while I got more and more interested in it and when I went away I bought three books…I was in a mall in Charlotte North Carolina, Books Are Us, a lot of books. So I went in there and I picked up an HTML dictionary and said "alright" so I picked out three books that looked the easiest, like HTML for dummies and I read it for my whole stay in Charlotte I read it.

However, as he learned more he saw a potential that fit with his own sense of himself as a creative person. By the end of the course he was fully engaged. He was engaged enough to spend part of his vacation reading independently so that he could improve his skills. He also corresponded via email with one of the authors of the books he bought to learn more about the underpinnings of his web site. When he returned home he started thinking

about what he could do with his knowledge and thought about teaching classes for other children (an idea his mother discouraged since he would lose his competitive advantage) and then decided he would start a business:
Interviewer: *So tell us about this business.*
Jamal: Oh yes, *Dynamic Web Design*, that started right after I finished this class, I couldn't believe I had to finish this class – I didn't want to get out of the class…I started a business making web sites…I started going to people and sending out flyers and stuff I started out I was going to put a web site on the web but that didn't work out as good cause I had to pay 70 dollars, I'm going to wait until I got a lot of money so I can build up, but besides that *my web site career has really worked for me,* I really like it, it's great.

This student's enthusiastic pursuit of an entrepreneurial new initiative led to new kinds of relationships in his community. An adult acquaintance provided him with some office space and he teamed up with another student whose special interest was graphic design. He also was left with additional questions. When asked what else he wanted to know he reported that he wanted to learn more about the insides of the computer to pursue his interests in being a computer technician or a web designer and to learn "where they make it, and how they make software like Microsoft. I want to learn how to do that." The desire to learn more is an outcome that we should assess more often.

Student 2, David: "It's good working with a partner, too, to help you sometimes"

Our second example is a student who took the first two courses. We interviewed David after he finished each course. David was one of the top scoring students in our post-test. Like Jamal, he had some opportunity to share his knowledge with his peers and with his father, a construction worker who was taking an online course to become a teacher. He also expressed an interest in a technology-related career. When asked if he like programming: "Yeah. That's one of my career choices. I don't know what I want to be yet but I know I want to do something with technology, because technology is moving so fast and that would be a good career. I want to be a computer programmer or an investment broker or something like that." His project-based experience in the first course offered him the position of being a team leader on the web-design project. He was articulate about his challenges and what he learned about collaboration in his advice to other student who might take on such a project: "Just listen to each other's opinions, and try to work as a group, and just stay together and don't get separated, 'cause then you won't get anything accomplished if you get separated". His valuing of collaboration persisted when he was learning to program Karel:
Interviewer: *So, you still work with your partner even though you aren't actually doing a group project?*
David: Yeah. Because if I get something working and she can't get it working, I will open up my source and she'll see how it's different or how it's alike. And she'll say, "Oh, I know why that happened, because of this." Or, I will say, "I know why…" It's good working with a partner, too, to help you sometimes. Because sometimes I get upset. If something's not working I'll get mad, I just go away from the computer for a few minutes and then come back, and while I'm gone away she'll just read over it and see what's the problem. When I come back I just look through it and she'll show me that maybe it's an error here or error there, and I just fix it . . . Sometimes we try to see what we actually have to do. Sometimes I might not understand and she will understand, or something like that. So, sometimes you say, "Oh, I've got to get Karel to pick up all the blocks and go to the end," or whatever. And then she will be like, "OK, well let's see how we can do it." We go onto the computer and we jot it down and whoever gets there first is like a victory. She'll be like, "Oh, I got it first. I got it first." After that we see if our coding is alike or if it's different or whatever. We can see even though it may be different sometimes, it still works.

Summary

In this paper we shared our ongoing design experiment work that attempts to support teachers as they teach fluency building courses. We provided data that examined the role of students' prior fluency building and communicative 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 a traditional assessment of learning, changes were observed in the breadth of learning resources students utilized. While the potentially transformative role of information technology 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 be 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. Other techniques such as social network analysis and longer term ethnographic studies will also be needed 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 much as by others. This notion of going beyond short term outcomes to measure broader aspects of learning such as an individual's capacity for self-development and community contribution has been recently raised as an important goal for other kinds of interventions such as grant-making programs (Dietz & Bozeman, 2000). These alternative models and measures may provide new tools for advancing thinking about systemic effects of project-based learning environments while contributing important insights for design.

The two brief examples of students who developed strong interests provide a richer sense of the ways in which students might broaden their learning and teaching contexts, though not all students were as enthusiastic as they were. However, many others also shared a deep engagement in learning, particularly in the context of the design projects and reported teaching others how to use HTML. More variability was observed in the second course when students were introduced to more formal programming suggesting that there is room for redesigning projects to better support long-term engagement. Overall, the data so far support our assumption that with sustained professional development opportunities relatively novice teachers can provide learning experiences that are generative for students and that might lead to productive trajectories of self and other development.

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