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Interest and Self-Sustained Learning as Catalysts of Development: A Learning Ecology Perspective

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Ecological perspectives · Learning · Life history · Parenting · Technology

Abstract

Adolescents often pursue learning opportunities both in and outside school once they become interested in a topic. In this paper, a learning ecology framework and an associated empirical research agenda are described. This framework highlights the need to better understand how learning outside school relates to learning within schools or other formal organizations, and how learning in school can lead to learning activities outside school. Three portraits of adolescent learners are shared to illustrate different pathways to interest development. Five types of self-initiated learning processes are identified across these case portraits. These include the seeking out of text-based informational sources, the creation of new interactive activity contexts such as projects, the pursuit of structured learning opportunities such as courses, the exploration of media, and the development of mentoring or knowledge-sharing relationships. Implications for theories of human development and ideas for research are discussed.

> *Interviewer:* How do you learn about computers?
> *Learner:* At the beginning I was reading magazines, surfing the net, I talked to my cousin Ian, my step dad, Uncle Jack, I took a course after school at Kingston Computers called Teen Tech. They taught you how to build computers and they taught you about small networks. That was another helper to my knowledge.
>
> Sixteen-year-old high school student

Studies of learning typically take place in school settings or labs, focus on school subject domains, and are bound to narrow time frames. By focusing on schools and labs as primary research sites we miss opportunities to investigate learning when it flows from the initiatives of the learner and his or her companions across time and settings. The sixteen-year-old who was quoted above is reflecting on the origins of

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his interest in computers and his strategies for gaining expertise. As his account suggests, learning about an area of interest can be distributed across resources including personal contacts, text-based resources, Internet exploration, and more structured learning opportunities. By the time of the interview, his knowledge acquired out of school was complemented by the completion of a sequence of high school computer science courses. Breaking out of a school-centric focus to consider the broader life spheres of an individual raises several interesting questions related to possible interdependencies between settings. For example, how does learning outside school relate to learning within schools or other formal organizations? When does learning in school lead to the independent pursuit of knowledge once the formal course is over? Once interest is sparked, what kinds of resources do learners seek out, and how might we conceptualize such processes of self-initiated learning? Finally, can we nurture learning by seeding informal learning environments with supportive resources that help sustain self-perpetuating processes?

Recent studies of children's use of computer technologies confirm the usefulness of looking both within and across settings, if we want to understand the development of interest and competence. Many students report that they use the computer much more often out of school than in school [Pew Reports, 2002], gaining access in their own home, a relative's home, or in the homes of friends. Others find computers to use in public spaces such as Internet cafes, computer clubhouses, or libraries. Out of school activities such as game playing with peers, apprenticeships with family members, being placed in a teaching role, or other kinds of informal arrangements allow for expertise development while simultaneously supporting aspects of identity development such as a sense of belonging in a community, feelings of competence, and interest development. The breadth and qualities of these activities are significant developmentally as are the roles and relationships that emerge across contexts.

Understanding how learning to use technology is distributed among multiple settings and resources is an increasingly important goal. The questions of how, when, and why adolescents choose to learn are particularly salient now, as there has been a rapid increase in access to information and to novel kinds of technologically mediated learning environments such as online special interest groups, tutorials, or games. It has become easier for those with computer access to find resources and activities that can support their learning on their own terms. However, there are also widespread concerns about equity. Although physical access to computing tools is becoming less of an issue, there are still stark differences among children and adolescents in access to learning opportunities that will help position them to use computers in ways that can promote their own development. In addition, there is the related concern that we convince a more diverse set of people to pursue advanced knowledge that will position them to work in technological design fields [AAUW, 2000; Attewell, 2001; Camp, 1997]. Design benefits from empathy with potential users, and it is important that those contributing to problem definitions and solutions come from a wider range of backgrounds than is currently the case. Schools are being asked to cultivate technological fluency, digital literacy, and other 21st century competencies [National Research Council, 1999]. Yet, as with other subjects, schools differ widely in the kinds of resources they offer [Warschauer, Knobel, & Stone, 2004]. A better understanding of how learning takes place across settings, and of the possible synergies and barriers between them, may help educators find ways to supplement school-based opportunities.

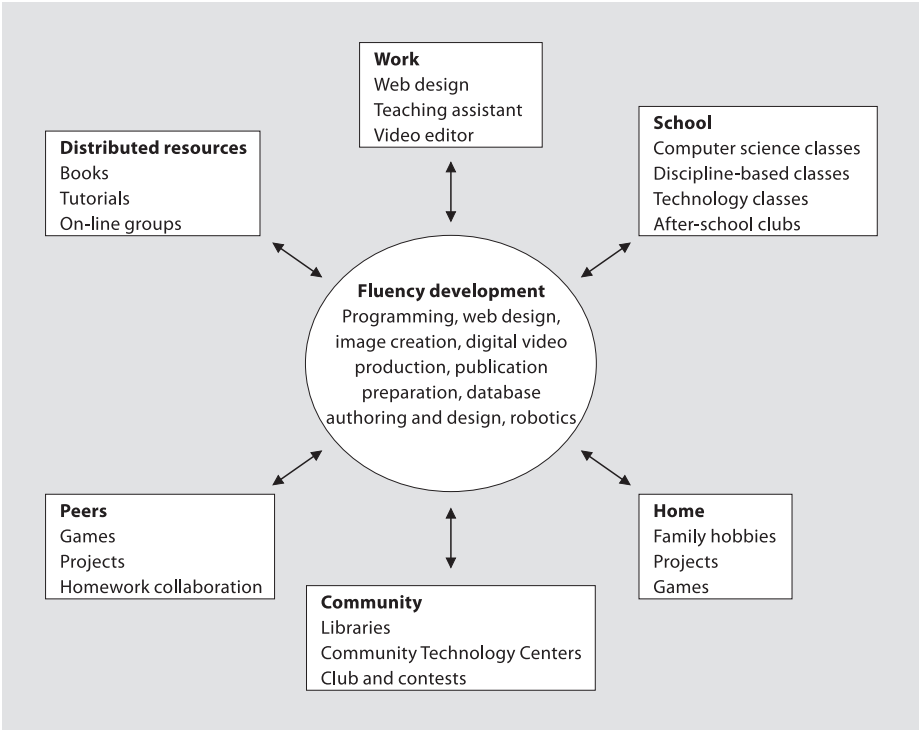

Fig. 1. Contexts of fluency development.

To make progress on understanding learning across the life spaces of home, school, community, work, and neighborhoods we need perspectives that help articulate questions that will advance theory and guide data collection. In this article, a learning ecology framework for studying the development of technological fluency is presented (fig. 1) along with conjectures about learning processes and case examples. A learning ecology is defined as the set of contexts found in physical or virtual spaces that provide opportunities for learning [Barron, 2004]. Each context is comprised of a unique configuration of activities, material resources, relationships, and the interactions that emerge from them.

The move to consider multiple settings as part of an individual's overall learning ecology came out of case-based observations drawn from classroom research [Barron, Martin, & Roberts, 2006] as well as a study of high school students using survey methodology [Barron, 2004]. The survey responses indicated that often learning was distributed over several settings and across many types of resources. More experienced students accessed a greater number of resources both in and out of school. Individual differences in the range and types of learning resources utilized were found even when physical access to computers and to the Internet were the same, suggesting that differences were due to variations in interest or resourcefulness. The results also suggested critical interdependencies between contexts. For example, few girls took programming compared to boys (15% vs. 65%). Of the girls that

did take programming, 75% had a parent that was in the computing field. This was true for only 32% of the boys. This finding suggests that there were home learning processes that were critical for these girls' decisions to participate in a formal class. While these survey data are suggestive, they do not indicate how experiences with new technologies came about or why particular resources were pursued.

Because the goal of this larger research program is to understand individual differences in learning outcomes and their relationship to access and use of resources across contexts, data collected needed to reflect processes of learning better than survey data. This article reports on that effort and is organized in four sections. First, I provide a brief review of the pertinent theoretical and empirical research. Next, the framework is outlined along with three conjectures about the development of interest and subsequent learning processes. Third, I share three portraits of adolescents who are active in creating learning opportunities for themselves to illustrate the validity of the theoretical conjectures. Finally, the set of cases are discussed in relation to the framework and directions for future research are proposed.

Theoretical Background

The learning ecology framework draws on ecological perspectives as well as constructs developed from sociocultural and activity theory. Ecological perspectives emerged from a desire to better articulate the interdependencies between child level and environmental variables in development and acknowledge the tight intertwining of person and context in producing developmental change [Bronfenbrenner, 1979; Cole, 1996; Lerner, 1991; Lewin, 1951; Rogoff, 2003]. In the early formulations of these perspectives, development was conceptualized as occurring as a result of micro-interactional processes across short time frames within contexts and across settings. Cross-context links, such as relationships between teachers at school and parents at home, were also proposed to influence development. All physical settings were in turn connected to more distal factors, such as work regulations, laws, or cultural beliefs.

Some developmental theorists went further and acknowledged that persons can play a role in their own development. For example, it has been suggested that from early on infants shape their environment in fairly passive ways through their temperaments, physical appearances, and very helplessness [Gottlieb, 1991; Scarr, 1996]. Some dynamical systems theorists have argued that environments change fundamentally with critical milestones such as the ability to walk [Thelan & Smith, 1994]. The world changes for the infant, in terms of its explorability, and the way this newfound freedom is exploited will elicit different kinds of attention from their caregivers. With age, the opportunities for individuals to propel themselves along unique developmental trajectories expand as they choose what to attend to, where to spend time, whom to interact with, and what valued ends to pursue. This independence affords greater opportunity to adapt one's environment and to more directly influence how others respond. Bronfenbrenner [1979] referred to these changes in person-environment relations as 'ecological transitions' and suggested they were both consequences and motivators of development.

Sociocultural, activity, and situative learning theorists [Cole, 1996; Engeström, 1987; Greeno, 1989; Rogoff, 2003; Vygotsky, 1978] articulate the ways that micro-

interactional processes work within distinct communities and how they relate to individual development [Lave & Wenger, 1991]. In these perspectives, the tools that have been created by prior generations serve as critical mediators of cognitive and social practices. These dynamic tools include language, writing, and other representational systems and can be adapted to meet current needs. For example, Saxe & Esmonde [2005] have shown the ways that collective practices can change when broader economic systems come into play creating new coordination problems. Their analysis shows how changes in how money was used in a community in Papua New Guinea required new collective practices that in turn were reflected in how individuals solved problems, demonstrating a coupling between historical and individual development. This analysis is particularly relevant to the learning ecology framework as it demonstrates that new tools can create shifts in interaction that play out in individual lives.

Research on Learning out of School, Identity, and Interest

The questions outlined in the beginning of this article about why, how, and when adolescents create learning opportunities for themselves have received little attention from developmental psychologists or learning researchers. However, we do know that a great deal of learning takes place out of school and that schools represent unique contexts for learning. Early work focused on important contrasts between formal and informal settings. In a landmark review of work on out of school learning Scribner and Cole [1973] define and distinguish characteristics of learning across contexts of school and non-school. Their review revealed how school-based learning is most heavily language based and information is taught out of context. In contrast, out of school learning more often relies on rich sensory information and affords learning through imitation and observation in the context of knowledge use. Another difference noted was the typical fusing of the intellectual and the emotional in informal environments due to the primacy of the relationship between learner and teacher, in contrast to schools, which are more impersonal. Research that looks more directly at the development of expertise in non-school environments has shown that structured social arrangements such as apprenticeships are often crucial learning contexts [Rogoff & Lave, 1984]. This work and later research have contributed to the important insight that cognitive efforts are coupled to tasks in specific situations [e.g., Scribner & Cole, 1973; Lave, 1988] and that practices are adapted to fit routine tasks and available resources. Several studies have documented the flexible and inventive practices that child street vendors develop to manage their transactions while failing when confronted with problems that have a similar content but are presented out of context in school-like forms [Carraher, Carraher & Schliemann, 1985; Nunes, Schliemann, & Carraher, 1993; Saxe, 1988]. Research to date suggests that sophisticated forms of competence do not depend on school, though practices of schooling result in specialized kinds of reasoning, such as being able to reason about problems that are presented out of context [Luria, 1971; Scribner & Cole, 1981] or inventing new mathematical representations and strategies when needed [Schliemann & Acioly, 1988].

Despite the usefulness of contrasting in and out of school learning processes, engagement, or performance, the need to resist simple dichotomies of learning in

and out of school was articulated early on [Scribner & Cole, 1973] and has been repeated in recent reviews [e.g., Bransford et al., 2006; Hull & Schultz, 2001; Resnick, 1987; Rogoff, Paradise, Mejía Arauz, Correa-Chávez, & Angelillo, 2003]. The problematic nature of making extreme contrasts is supported by empirical research that shows that people bring learning practices and knowledge across boundaries under a range of conditions. Schools can be places where informal learning processes such as observation, imitation, collaboration, and apprenticeship take place [Rogoff, 2003], while processes that we typically associate with Western schooling such as quizzing or memorizing can be observed in homes and among peers engaging in non-school learning [Henze, 1992; Senechal & LeFevre, 2002]. There is a growing consensus that we can come to understand more about learning if we document both similarities and differences between learning processes inside and out of school and focus on the study of the complex relationships between them [Hull & Schultz, 2001]. Thus, answering questions about the origins of self-initiated learning will require a focus on the emergence of activity and how it is developed across contexts. We have little information on synergies between participation in technologically mediated informal learning activities and more formal educational environments and the conditions that make boundary-crossing activities possible.

Studies of family interactions in homes and museums make clear the importance of understanding the role of intimate relationships in learning. For example, investigations of dinner time conversation in middle-class homes have provided important insights into how ways of talking and thinking are socialized not only by schools but at home [Ochs, Taylor, Rudolph, Smith, 1992] and how non-school activities such as eating dinner can be opportunities for the practicing of school-like talk. Crowley & Jacobs [2002] have introduced the idea of 'islands of expertise' to reflect the fact that young children often develop considerable knowledge about topics of interest during the preschool years and that these areas of expertise become foundational for the acquisition of school subjects. They give the example of a child whose interest in the topic of trains was sparked by a book. Book reading was followed by trips to museums and viewing videos related to trains. Over time he and his parents built up a great deal of shared knowledge including vocabulary, schemas for train scenarios, and knowledge of mechanisms that allow for train travel. This shared knowledge in turn can support rich conversations that include explanations, elaborations, and analogies to related domains that prepare the child for future conversations with non-family members. Building an island of expertise supports the development of more abstract knowledge within the domain but also sets in motion other social processes such as parents and peers recognizing the interest and then engaging in conversation about it or providing resources such as books, toys, and equipment that encourage activity and further learning. Palmquist and Crowley [in press] have carried out comparative studies of family visits to museums where the children differ in their dinosaur knowledge. They show that museum visits provide occasions for some children to take on the role of an expert as they guide their parents around the exhibits and explain what they see. Such museum guiding is a cognitive activity that enhances conceptual knowledge through the mechanism of explaining [Chi & Bassok, 1989; Webb, 1985, 1989] and simultaneously builds up a sense of self as one who is knowledgeable.

Attention to the role that identity development plays in sustaining the interest that drives learning will also be key to a better understanding of self-initiated learn-

ing. The studies of learning with peers and family members make it clear that it is not only conceptual knowledge that is developed out of school but broader aspects of becoming a person [Nasir, 2002]. Beach [1999] highlights how learning can result in a sense of being someone new; he distinguishes this kind of transformative learning that involves shifts in identity from everyday learning and refers to it as a consequential transition. Relevant to the discussion here is the important notion of agency in many accounts of identity formation. For example, Lave [1996] described identity formation as 'craftwork.' Holland, Lachicotte, Skinner, and Cain [1998] build on Bakhtin's [1981] notion of authoring the self to articulate how identities are dynamically constructed – through a process of constantly being addressed by and answering back to a 'figured world' that offers different possibilities for the self. In a similar way, Ochs [1993] argues that language use marks and contributes to the establishment of an identity. Gee [1996] defined 'ways of behaving, interacting, valuing, thinking, believing, speaking, and often reading and writing that are accepted as instantiations of particular types of people by specific groups of people' as 'big "D" discourses' (p. viii). Discourses are embedded in social hierarchies and thus linked to issues of power in society. Peer relationships can also be powerful contexts of socialization and learning [Macoby, 1990]. Discourse-based studies of peer groups reveal the unique ways that children socialize one another and draw on observed power dynamics and social norms while at the same time inventing new language genres, games and rituals [Goodwin, 2002]. These informal interactions provide a context for the development of complex negotiation skills as language is used to develop and maintain alliances [Kyratzis, 2004] and shape later interactions within school [Eckert, 1989].

Research on the topic of interest has made progress in characterizing different levels of engagement, such as personal versus situational interest, with the former being more enduring, as well as begun to characterize phases of interest development [Hidi & Renninger, in press]. Other investigations have shown that there are relationships between interest and knowledge [Alexander, 2003; Renninger, 2000] and that interest is connected to positive affective experience [Schiefele, 2001]. While some work is being done to understand how an interest changes from one form to another, much of the work has focused on the role of internal motivational processes such as basic needs of competence, autonomy, and relatedness [Krapp, 2002, 2005]. The learning ecology framework foregrounds ideational resources in the emergence of interest as an analytic focus and the self-initiated processes of learning that take place across context as new opportunities for activity and knowledge building relationships are perceived.

A Learning Ecology Framework for Studying the Dynamics of Interest-Driven Learning

A learning ecology perspective foregrounds the fact that adolescents are simultaneously involved in many settings and that they are active in creating activity contexts for themselves within and across settings. While interactions within co-located settings are critically important for development, it is also clear that there are learning processes that involve the creation of activity contexts in a new setting or the pursuit of learning resources that are found outside the primary learning setting. The

framework builds on prior studies of informal or out of school learning in recognizing the variety of literacies, practices, and forms of knowledge that are developed and employed out of school as children and their companions pursue activities of interest to them [Hull & Schultz, 2001]. It takes into account that boundaries are often more permeable than many theoretical discussions might suggest, and that children and adults often draw on multiple cultural forms as they meet their current needs, wherever they happen to be. Finally, it recognizes that learning can be intertwined with processes of identity authoring and that when it is, secondary developmental processes can emerge from more distal learning events.

Conjectures

Because the topic of my investigation is the development of technological fluency, there is a special focus here on how new technologies can help make boundaries more permeable and allow for new kinds of agency in learning. Ecological metaphors have recently been applied to other studies of technology-rich environments [Brown, 2000; Looi, 1999]. For example, Nardi & O'Day [1999] introduced the idea of an information ecology. As they put it, 'an information ecology is a system of people, practices, technologies and values in a local environment. Like their biological counterparts, information ecologies are diverse, continually evolving, and complex.' The current definition of learning ecologies shares with the definition of information ecologies the idea that both relational and material resources are important in any socio-technical ecology [Nardi & O'Day, 1999; Brown, 2000] and it implies a dynamic learning system open to multiple influences.

The framework raises new questions about learning by identifying for study the ways in which adolescents create learning opportunities for themselves, or capitalize on the ones offered, once they become interested (including deciding to take school classes, find books, or create projects). It highlights the usefulness of documenting the multiplicity of pathways among learning contexts that learners might take and raises questions about the emergence of interest, specifically, how ideational, social, material or identity resources spark or inhibit it and how processes of appraisal of fit between a topic and one's sense of self or identity are implicated. Three conjectures about the dynamics of interest and learning are described below along with some ideas for how we might investigate these conjectures empirically.

Conjecture 1: Within Any Life Space, a Variety of Ideational Resources Can Spark and Sustain Interest in Learning. Ideational resources might come in the form of the ongoing activities of other people, conversations, books, computer programs, projects, or assignments. This view of interest differs from most person-based accounts [e.g., see review by Krapp, 2002] in its attention to how the specific activities, experiences, and social networks that a person encounters are important in the genesis and sustaining of interest and engagement. *A productive approach is to examine pathways of participation and to provide an account of the kinds of events, activities and processes that spark interest in learning.*

Conjecture 2: People Not Only Choose but Also Develop and Create Learning Opportunities for Themselves once They Are Interested, Assuming They Have Time, Freedom and Resources to Learn. These strategies include seeking out informational resources, creating a new project, signing up for a course, or finding

learning companions. These strategies of self-propelled learning are likely appropriated as cultural practices of others and adapted to serve one's own purposes. Work on intentional learning has focused on micro-level processes such as self-explanation [Chi & Bassok, 1989] or classroom knowledge-building processes [Scardamalia & Bereiter, 1994]. *Categorizing learning strategies at this broader level of analysis may serve as an important design resource and contribute to theories of informal learning.*

Conjecture 3: Interest-Driven Learning Activities Are Boundary-Crossing and Self-Sustaining. There are likely to be multidirectional relationships between learning activities across contexts when they are taken up as a result of interest. For example, interest in a topic and some knowledge might be developed at school and be followed by new knowledge-producing activity at home. Related activities might emerge in the community affording additional knowledge. When the learners return to school, related courses might be chosen or their expertise might be newly recognized and called upon by peers or teachers. Thus, a learning ecology is dynamic, subject to intervention, and its growth might be assessed. To evaluate this idea, longitudinal data should be collected. *Developing ways to chart changes in a person's learning ecology, including consequential transitions, could be useful for advancing theories of learning and have practical applications for assessing the productiveness of educational interventions.*

Case Portraits of Learners Learning across Boundaries

The idea that persons help constitute the very environment that they grow within is complex and difficult to conceptualize in terms that are subject to empirical investigation [Cole, 2000]. There is a tendency to slip back into thinking of nature and nurture as separate forces rather than intertwining aspects of the developmental process. Part of the difficulty we face is designing studies that do justice to this complexity. Studies of learning often occur across very short time frames and focus on more narrow outcomes. Alternatively, analysts take on the life course as a unit. We have fewer approaches that are geared towards more intermediate time scales. An important next step in this research agenda is to specify the self-perpetuating processes that underlie learning and development at more mid-level time scales.

While ecological and activity perspectives provide conceptual resources for thinking of development more holistically, they also raise important questions about how we might study developmental processes across time in ways that capture the dynamics of a system. For example, Lemke [2000] asks, 'how do we study ecosocial processes on timescales longer than a few hours?' This question comes out of an interest in reconciling and connecting analyses across different scales of time. Cole [1996] proposed that we begin to study not only micro-genetic processes, but also those that are meso-genetic (extended activity) and ontogenetic (biographical). Some theoretical constructs have begun to productively describe developmental processes at these more mid-level time frames. Crowley and Jacob's [2002] islands of expertise theory is one example. Though focused on preschoolers, this idea may be extended to older children or adolescents. However, in contrast to preschoolers, older children have greater independence in their learning in that they are typically able to read,

have the opportunity to select books or other media, and in middle school can choose elective classes. In addition, parents may support attendance at summer camps, after-school clubs, or other community-based contexts where classes are offered. Thus, the specific learning processes may differ between preschoolers and adolescents. In addition, with age children expand their social networks and peers become centrally important in the child's social ecology. A child's friends and their parents may offer a space for activities and conversations not available in the child's own home. These capabilities position children and adolescents to participate in new activities, practices, and roles that they find compelling, without having to completely depend on the support offered by caregivers.

Although these mid-level learning processes are ubiquitous, we have no system at hand for categorizing them, studying their influence, or finding ways to account for them in our theories of human development. The learning ecology framework may contribute to this agenda in a modest way by providing some examples of the kinds of moves that adolescents make to create new activity contexts for themselves that then support their learning. The examples I share represent the development of activity contexts within relatively short time frames (weeks, months) and their effects represent small changes rather than grand stage-like shifts. However, they were selected because they were strategic moves that were potentially consequential for the adolescents with respect to growth in competence, beginning a sequence of courses, or enhancing aspects of their sense of self and future selves [Beach, 1999; Cross & Markus, 1991].

Analytical Perspective and Settings for Data Collection

The use of interviews as the primary data source in this paper was a choice based on their utility in illustrating phenomena related to the three premises underlying the learning ecology framework. These interviews are summarized to create portraits of learning about technology in a genre that has been called technobiography in a recent work [Henwood, Kennedy, & Miller, 2001]. A life narrative approach allows us to chart a learning history in terms that go beyond metrics such as numbers of courses taken, including 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 human development [Mishler, 1996]. The ideas underlying the learning ecology perspective were generated through interviews with youth and are thus grounded in accounts of learning as offered by adolescents, as the method of grounded theory advocates [Glaser & Strauss, 1967]. The goal is to provide illustrations of the phenomena rather than prove their ubiquity. Survey studies, randomized experiments and design experiments are under way that will deepen the empirical support for these ideas.

The examples in this paper are drawn from two different research projects that address the development of technological fluency. One of these projects was an international collaboration between a research group at Stanford and teachers and education ministry officials in the country of Bermuda [Barron, Martin & Roberts, 2006]. The project was a design experiment [Brown, 1992] that involved curriculum

Table 1. Types of self-initiated knowledge-building strategies

Type	Example strategies
Finds text-based information	Identifies and reads books, magazines, or Internet-based information
Creates interactive activities	Completes tutorials, creates new projects, starts a business
Explores media	Experiments with programs, surfs the web, analyzes designs of others
Seeks out structured learning	Signs up for courses in or out of school, joins a club
Builds knowledge networks	Joins special interest group, finds mentors, has conversations with peers or relatives

development, professional development, and assessment of student learning (for more details, please see http://bermuda.stanford.edu/). The other project involved studying technology use as it relates to the development of technological fluency by middle and high school students in the Silicon Valley region of California. Two communities are being studied. One is relatively affluent with respect to access to technologies, level of parent education, and knowledge about new technologies. The other community is more diverse economically and has a high proportion of recent immigrants to California, mostly from Mexico. Both interviews and surveys were used in these studies to characterize individual differences in interest in, access to, and experience with new technologies. In all, the dataset includes surveys or interviews with approximately 400 students. A smaller set of case studies with more in-depth interviews are also being carried out. I have chosen to profile three students in this paper and have selected examples that provide more than one data point in order to address issues of continuity in interests and learning opportunities across time. I do not attempt to generalize as the examples occur at varying time frames, are based on retrospective accounts, and have been taken from different studies. They have in common the fact that they are all examples of adolescents seeking out resources or creating new activity contexts in order to learn about how to use computers in creative ways. Though the cases I share in this paper all represent generative cross-context pathways, I am equally interested in documenting cases where there is interest but greater challenge in finding resources.

These examples illustrate three pathways for the development of interest and knowledge that include pursuit of further learning outside school. In the first, interest arises at school and is carried over to home and community contexts. In the second, the origins of interest can be located during informal learning activity with friends, but it leads to the pursuit of classes in school. The third case represents a trajectory of activity that begins at home and leads to learning activities in out-of-school classes, in the community, and then at school. From these examples and others in my dataset, I identified five broad categories of knowledge acquisition strategies, such as creating new projects or seeking out text-based information (table 1). They do not capture all learning processes (e.g., aspects of identity work or parental guidance are both important learning processes) but are common strategies that adolescents report using to learn. For each example, I provide a narrative and then discuss the case in relation to the three conjectures described earlier.

Example 1: Classroom Learning Sparks the Creation of New Learning Activity

Jamal was a participant in the classroom research project located in Bermuda. He was first interviewed after taking the introductory computer science course during his first year of senior school, the equivalent of the freshman year in the US high schools. He was interviewed again 1 year later. His grades were considered to be an underestimate of his potential by his computer science teacher. He reported that before coming to senior school, he had little understanding of computers and what you could do with them, and in fact knew nothing about the Internet:

> I: When you took the course, did you have a lot of experience with computers?
> J: No, not at all. When my mom bought me a laptop I didn't know anything about web design or HTML – all I knew about the computer was it was something to type to … I did not know anything about the Internet or nothing like that until I came here, to Burton Hall [his public high school in Bermuda].

Most of the Bermuda students have a computer at home as well as Internet access. It is a major site for international businesses that are able to obtain offshore tax status. Tourism is also an important aspect of the economy. Although there are clearly huge differences in income between those who work in different economic segments, on average the standard of living is high. Many Bermudians find ways to work in more than one context in order to maintain a comfortable lifestyle and providing computer access to their families is a common investment. Having personal access to a laptop despite little opportunity to learn about how to use it at home may be due to the fact that adult knowledge of computing in Bermuda is quite variable. Few parents of students in the public schools hold jobs that require a high level of technical knowledge. In one recent sample of almost 100 Bermuda students, we found that over half of fathers worked in trades such as carpentry or painting, and while about 60% of mothers worked in office settings, none were in a profession that involved the computer industry [Barron, Martin, & Roberts, 2006]. Most of the students in this study reported that they knew more than their parents about computers and that they frequently teach them, rather than the other way around. Jamal reported that he did not teach his mother, mainly because she had little interest. In fact, Jamal himself experienced a major shift in his engagement with the course content that he articulated in the beginning of the first interview.

> I: So tell us about it, you said you really got excited …
> J: Yeah, 'cause Mr. Hanley 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.
> I: Who were you with?
> J: I was with my mom. She was excited 'cause I was really doing something besides playing games with computers so I started up reading it and got more and more interested and I said, 'alright I can make something out of this,' so I started going to the computer more and more, I spent a lot of time making web pages … I went to the man's site who wrote HTML Goodies, Joe Burns. It was almost like the book except it was a site and I asked him little things, questions like and he emailed me back.

I: What kinds of questions did you ask?
J: Like how did he make the backgrounds for his page, what tools did he use, and he told me everything.

After the course was over, Jamal decided to create a business and viewed this activity as a way to keep learning. It was one of several ideas he had – the other main idea he had was to start a class in HTML for younger children. However, it was pointed out to him by his mother that he would then increase his future competition if he wanted to work in the web design space.

I: Tell us a little bit about this business. So when did that start?
J: 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: You had more to do …
J: Yeah. I was like 'alright,' I started a business making web sites, I said 'okay I can make some money out of this,' I was like 'alright,' since everybody needed a web site, everyone was going to have to go on the Internet, so I could make some web sites for some businesses, not real big businesses, I said 'alright, I can do some small business web sites,' I started going to people and sending out flyers and stuff. When 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.

Jamal was able to elicit the confidence of an adult friend who invited him to share his office:

J: I went down there and I told 'em, 'I make web sites and stuff.' Like me and the guy were like friends. He said 'you can go in my office 'cause I don't really use it that much just to teach the students,' and I'm like 'alright,' and I started making his web site and he's like 'you got talent, you can really make something out of this,' and I'm like 'I know I know.'

This focus on starting a business was not the only interest that emerged from the class:

J: Well I would like to know more about the insides of the computer because when I grow up I'd like to be either a web designer or a computer technician … I mean more, like how to put it together, where they make it, how they make software like Microsoft. I want to learn how to do that.

By the second interview, he had changed the name of his business from Dynamic Web Design to E-magine. He was still struggling with the issue of raising capital for the business and had generated a new plan to have ten of his peers and future business partners each sell a web site design for USD 450.00 and then contribute this money to a base fund for running the company. When probed, however, it was clear that he only knew one or two people that had the requisite skills and he wasn't sure how to ascertain who might really be 'deep into it.' Despite his lack of concrete progress with the business, he kept his idea alive by deepening the plan whenever he had the chance. For example, in his business classes he would use E-magine as a focal context when given an assignment such as setting up a spreadsheet or determining revenues and he used it to organize a portfolio in another class. By the second year, there was also some competition for his time outside of school. He had become seriously engaged in writing rap music. He was quick to distinguish his lyrics from others: 'I don't write about

violence, sex, or cussing.' He viewed a career in music or in web design as competing futures as he didn't know if he could manage both of them simultaneously. During the second interview, he reported a recent conversation with his mother about possible colleges to apply to. His preference was for a technical school.

Analysis

Emergence of Interest. Jamal traces his interest in HTML and web design to his experience at school in an introductory computer science course. Unlike the two forthcoming cases, Jamal did not have someone at home who possesses expert knowledge. Jamal's narrative account of the evolution of his learning activities draws attention to the dynamic nature of interest and suggests an appraisal process in which there is active assessment of how a topic is fitting in with some aspects of one's sense of self – in his case being a 'very creative person.' He went from a dismissal of it as tedious and not worth the effort to a sense of excitement about its potential to help him realize his creativity. He imagines a future self that might exploit his knowledge of HTML to earn money and he engages in some analyses of how all businesses will need some kind of web site in the future. He imagines that he might be able to fill that need. This imagining of a future self in action has been called identity craftwork by Lave [1996] and self-authoring by Holland et al. [1998]. The imagining of a future self and the role this plays in decision-making has been identified by some psychological theories of identity development [Cross & Markus, 1991]. In Gee's [1996] analysis scheme, Jamal is participating in an aspect of a big 'D' discourse – taking on the values and stance of a technological entrepreneur, becoming recognized, as Jamal happily reported, as a 'geek' or a 'freak.'

Creation of Learning Opportunities. Jamal is certainly what has been called a 'committed learner' [diSessa, 2001], investing his discretionary time to learn and financial resources to buy books to support that learning. His pursuit of more information is illustrated by the speedy uptake of not only traditional resources like books but also the Internet to learn and to communicate with more expert others. Jamal uses three of the learning strategies listed in table 1. The first strategy he uses *(finds text-based information)*, once he acknowledges his interest, is to buy several resource books on HTML. The second one *(builds knowledge networks)* is exemplified by his attempts to broaden his social network by making a personal contact with a book author, querying him on specific aspects of web design including tools and techniques. He also makes contact with potential customers for his web design business. His ability to make these connections is in turn dependent on his prior learning in school and through reading. He is able to use the technical terms and present himself in ways that are responded to positively by experts or those in a position to share resources. Community members such as his friend who offered him office space perceived him as having knowledge to share after being shown some of his work. He was able to leverage his knowledge of terms like 'frames' and 'background' to communicate with the book author. His use of technical language signals his growing competence and contributes to it by extending the kinds of conversations and interactions he is able to have. The third process we see *(creates interactive activities)* is shown in his move to create a business, because, as he put it 'I couldn't believe the class was over.' This process is quite interesting as it is an example of projecting oneself and learning needs into the future and realizing the value of a real world context for motivating knowledge acquisition.

Boundary Crossing and Bi-Directional Influence. Jamal's interest and learning cross the boundaries between school and distributed environments and between home and school. For example, he brings this interest home and it serves as a conversational focus between him and his mother. Not only did his mother express her happiness that he was doing something with computers other than playing games and (probably) supported his book purchases, but she was also active in helping him think about different ways that he might use his newfound knowledge, drawing his attention to the need to think about future competition and the need to keep his knowledge to himself rather than sharing it by organizing classes for young children. Even before this interest emerged, she had bought him a computer, perhaps anticipating his interest, but certainly giving him opportunities to learn to use it on his own. Note how in this exchange she socializes him into a way of thinking about his skills in the marketplace. It is also clear in this example that there is a bi-directional flow of interest and knowledge. Insights gained at school lead to his seeking out new resources, which he then brings back to school and shares with his teacher. He also brings his interest and imagined future activity to his business classes, providing a context for what otherwise might be an impersonal school assignment. His new skills allowed him to move outward and establish new roles for himself in the community. By sharing some of his work with an adult friend, he is recognized as having 'talent' and encouraged that he might 'make something out of this' and even given some office space in which he can start working. Jamal's business project might be said to function as a boundary object of sorts though perhaps it might be called a *self-initiated boundary activity.* Star & Griesemer's [1989] use of the term 'boundary object' was restricted to documents or terms and referred to their use as mediating communicative tools for cross talk between people from different communities. The project activity and imagined future activity are not boundary crossing in the sense of bridging the worlds of different people but rather function as a bridge among the different life spaces that Jamal inhabits. This phenomenon shares aspects of what Stevens [1999] and Gutiérrez, Baquedano-Lopez, and Tejeda [1999] have referred to as hybrid activities that combine elements of play and school-like learning or school and professional activity. It differs in that rather than being an intervention designed by an educator it is an activity initiated by a learner.

Though his interest was still strong, the second interview revealed that despite his enthusiasm there were some real-world obstacles for him to overcome. Resources needed to sustain the activity, such as money and colleagues who could help, were more challenging than he originally anticipated. In addition, he found new creative outlets that were competing for his time. Despite these challenges, he managed to keep the idea alive, ironically, in school.

Example 2: Informal Learning with Peers Leads to a Desire for Formal Education

Stephanie is a middle school student and was interviewed twice, once at the end of the seventh grade and once at the end of the eighth grade. She grew up in California, in a community that employs many engineers and programmers. In fact, her mother is a patent attorney and her father works in the silicon chip industry. She shares a computer at home with her parents. She mentioned she uses it the most and that her parents consider it to be hers though, she claimed, they do not verbally acknowledge that ownership. Despite her parents' participation in technological jobs,

she feels that they don't understand her technology use because they were both born and raised in China and had little access to any technology there.

> S: My parents are just so confused because they just never had this because they lived in China during the Cultural Revolution so they didn't have radios. My having a computer with Internet access and my printers and scanner and MP3 players … all of this is just so foreign to them, but it's just part of my life and I take it for granted.

Stephanie attributes the origins of her interest to her friends and their participation in an online community called Geocities. In this environment, participants are provided with tools to create web sites or blogs. She began this informal activity when she was 11 years old and was 12 when she decided to take formal classes based on this growing interest.

> I: Can you tell me the story of you and computers? When you started using them and that kind of thing.
> S: Okay, okay, I have always have had friends who were pretty interested in computers. So um they started doing some web design in Geocities using HTML and then they told me it was really fun so I joined in and they sort of taught me what was going on, and so that is where I learned HTML. I started making my own web pages then I started joining classes like industrial technology and programming because it was like becoming an interest for me and like ya.
> I: Where do you use them most now?
> S: I probably started out using them the most at my friends' houses or at my house because we would just get together and work on our pages. It was just a lot of fun. And then I started doing more at the library because I started going there more and they have computers there that you can sign up and use. But now I'm probably working most at school because I'm taking so many classes.

In both interviews, Stephanie linked her interest in computers to the capacity to create with them. She described herself as liking to draw and she mentioned that she would create web pages that had links to her art. She also illustrates the stories of her friends and they in turn illustrate her story.

> I: Where or how do you have most fun learning?
> S: With my friends. Programming can be challenging [in class], like you have a challenge set out for you but it is also fun with your friends, you can be creative and like use different codes, computer codes, or computer languages to make fun designs and you can be proud of it and post it. Putting together a page its like art almost, because even before I got interested in computers I have always liked to draw and when you put together a page with code it's like painting a picture or something, and when you have the end result it is pretty cool to see that you made this and typed it out and you got it to do what you wanted, that you were like successful and I think that is the best part.

By the seventh grade, she had developed the idea that her future job would have some tie to computers. For example, in both a survey response and in an interview she mentioned biotechnology as a possible career choice. In the seventh grade, she managed to take programming, industrial technology (a design course in which computers are used to meet assigned challenges), and web design. Like her use of computers, Stephanie described her learning about computers as distributed across contexts and she reported bi-directional teaching relationships. She both learns from her parents (despite their gaps in understanding her constant use of computers) but also shares knowledge with them. She learns with and from her peers both at school and at home.

I: Do you learn most from them (parents) or on your own, or from books or web sites?
S: I think I learn most from my friends, then classes, and I'll share with my parents and then they will share some things I don't know with me. Like my dad is always teaching me, then I'll teach my mom or something. When I was actually in the class I was learning with a friend. We did everything together. Some things were really hard for me to get and some things were really hard for her to understand. We stuck together the whole time and we explained to the teacher and she was really flexible so we could help each other.

By grade eight, she had already taken most of the technology classes offered in her school and as she put it 'I decided to branch out on my own.' Her father had also proposed to her that she develop a family web site and asked if she could help him design a web site for his planned start-up company. She continued to express a persistent interest in learning more and had found several new communities online that she lurked in for picking up knowledge and techniques. Her friends discovered some of these sites. She also reported a great deal of exploration: 'I Google everything. Sometimes I'll just be randomly going through the Internet. I really like doing that.' Later she comments: 'Google is my life.'

I: Are there sites that you learn things from?
S: Yeah. For digital art a lot of the people tell you what they used to make it, so they will use actual terms and stuff, which means very little to me, but I'm hoping when I actually get started I will be able to use their processes to do it. Some of them post how to do this. Sometimes the picture they post is a step-by-step thing that they drew. You see the layers.

Her interest in images and art creation in particular had deepened but she did not have the software tools that she wanted to learn or the hardware (a drawing tablet) that she felt she needed. She became particularly interested in 'skins' and in digital art. In the summer before the eighth grade, she became involved in Xanga, another online blogging community.

S: I started Xanga during the summer … At first I was just tentative and I would change the background color or the text color or the link colors to suit my preference, but then I discovered skins and then I went crazy. There is a lot of digital art. I think it can be really beautiful. Some of these people do this for a living. What they post is what they do in their free time. There are a lot of these boards and you can join them for free and if you want to submit something … I don't know exactly how it works because I've never done it myself, but you can go to a site and they have a tablet and you just draw basically, but it is a lot easier if you have a tablet. They have some paintbrushes that you can go over. I don't know the actual technological terms, but they have different tools that they use. They have watercolor and everything comes out sort of painted and light. If I go to the board and I'm not a member I can see what they've submitted, but I can't actually paint myself. If I get a tablet I hope to join one of the boards because that would be a lot of fun.

A main learning strategy involves looking at others' work and examining the source code:

S: That was when I was first really getting into computers, I think. Then I got a Geocities account and I started looking at skins and how they did it, so it's really hard to just look at it and you cannot piece together how they did it really 'cause it's all … there are no actual words. For some … I discovered this and it amazed me, when they make the skin they'll put the source text that you don't see when you open the skin on the Internet, but if you looked at the source it's there. They tell you what they did. They actually say 'you can't change this

because it will mess up the whole thing. This is where you add your picture or music.' That really helped me. I would start piecing together things. Going to sites with skins and using them for my Geocity, adding my own music and adding my own images and my own blog screens.

I: Did you ever use books?
S: They always looked so complicated. My mom had one on Java, but it was so intimidating. After that I never really looked at a book again. The language they use is expecting you to already know the terms. If you are just starting out it is really bad … I like to get more hands on. I like to plunge into it more. The book goes so slowly. I like to see the final and then go back and see how they made that final and then connect … A lot of the time I can take pieces where I can see that is what they used to add the picture and I can even cut and paste it and change the picture heading and add my own picture. It takes a lot of time, but it's a lot more interesting to me than looking at a book and doing it step-by-step.
I: If you could learn anything what would you learn and why?
S: I want to learn more about, not only have the computer draw things for me, like what we are learning now, but um even expand what I can get the computer to do, just by typing the code or making a program and take the parts of it and combine with something else and get a bigger result and take the codes and really be more free with them. Like now we are learning specified codes to get specified results. If we really, really got to be comfortable with these codes then we could take the parts and type up our own programs and get even bigger results.

In high school, Stephanie plans to take art, photography and Java programming.

S: I'd like to (take programming) because … like on our school web site go to the Japanese teacher's site and her students actually created a Flash opening for her site and it's really cool so all the other language teachers are kind of intimidated, but it's really cool.

In her eighth grade interview, she repeated that she had thought about becoming a doctor but is feeling that she would like to do something 'on the creative side of her brain'.

I: When you grow up what do you imagine yourself doing?
S: I think I've mentioned this before, but my parents and I have always thought I would become a doctor and go to med school. I don't know because my strengths aren't exactly in science and math. I do well, but I'm more on the creative side of my brain. I like to read. I like to make up stories. I like to draw. I like to listen and play music on my piano. I go online and search for sheet music and print it out and play on my piano, so you see how my life connects. I had to do this thing over the summer with my church. I was in a cappella group so singing with that group. This is hard. I had to download this thing called … what was it called? I still have it. It was free. They allow you 25 songs on it and then you have to buy it, but that was more than enough. We had to type up our musical score into it and it was really handy because you had to cut out pieces 'cause you could have it only play the sopranos or whatever. It helped a lot. I would surf the web and listen to it constantly in the background, so I memorized it. I really liked this song and I wanted to learn to play this song on the piano, but the piece was so difficult looking at the sheet music I printed off the Internet, so I went to that demo thing and then I typed it up on the demo and then I could take it treble clef and bass clef and violin accompaniment and take it apart so I could listen to it one at a time and slow it down and speed it up and that helped me learn the piece and I could play it.

Analysis

Emergence of Interest. In this case, Stephanie's interest was born in a peer context where a web authoring activity was a focus of their interaction. Her specific interest at first was in learning HTML but generalized to include programming, and the use of technology in various design pursuits. In contrast to Jamal who has a practical aim for his web design knowledge, Stephanie seemed more interested in the expressive potential of the technology, and her imagined future knowledge state reflected increased power and generativity of computer languages, or as she explained, she would like to 'take the codes and really be more free with them.' In both interviews, she aligned her interest in technology with her previous interest in art, and in the second interview also revealed that both of her grandfathers are artists. However, she also likes to explore and is quite active in looking for tools on-line that can help her accomplish other goals such as learning to sing, play the piano or do research for school.

Creation of Learning Opportunities. Her interest was generated within a playful, peer-based activity and led to a sustained interest that was then pursued in school *(seeks out structured learning).* It is of note that her school is unusual in the breadth of technology classes it offers. Few middle schools or high schools offer such a broad array of courses. Within school, she described the importance of her friend in class who was her constant learning partner. She also described learning conversations with her parents where sometimes she is the teacher and sometimes the student *(builds knowledge networks).* While clearly her parents are already in her social world, they are also playing a very specific role for her as learning partners. Similarly, her continuing association with a group of friends who 'were pretty interested in computers' maintains a social network where she is supported by conversations and joint activity. Stephanie has also attempted to use books *(finds text-based information)* but in her case found them wanting as learning tools. She felt the language to be a barrier and they were not paced in a way that she enjoyed, as she described, 'the book goes so slowly.' She preferred to do much more exploration and learned from the examples provided by others on her favorite art community site or from web sites more generally *(explores media)*.

Boundary Crossing and Bi-Directional Influence. Stephanie's learning is distributed among her friends, her classes in school, and on-line learning resources. The content and skills she learns move easily from peer learning to school to home and probably back again. Stephanie's intent in taking the web design course was to better design her web sites, and it is quite likely that she had fewer problems in class due to her prior work on web design out of school. Stephanie showed us her new skills in creating animated movies in a third interview, and she was the first in her peer group to learn this. She was planning to show her friends after she had a finished product. Like in the case of Jamal, her growing competence was recognized by an adult, her father, who has requested that she help him create a web site for a new start-up venture.

Example 3: Home to Community to School and Back Again

Craig attends the same middle school as Stephanie and was interviewed on two occasions. His mother and father were also interviewed, as was one of his learning partners, a videographer, who became a mentor through weekly church-filming activity. In the 7th grade, he found his way into the programming class. However, his

interest in computing had its origins long before school started when he would watch his father work on the computer.

> I: What do you remember in terms of when you were introduced to a computer?
> C: I don't remember like the first time, but I do remember some early experiences with computers. I thought they were fascinating, how they were such a little machine but could do so many things … I thought it was fascinating … I always watched my Dad kind of on the computer and how he would do different things, open different things. I just thought it was amazing how it did everything and it did it so quickly.

His parents helped fuel this interest by buying robotics kits and various kinds of software. Craig's father, an engineer, recalled that occasionally he would sit down with Craig to do projects but that he learned mostly on his own.

> F: When he was like eight or nine we bought him Lego Mindstorms, which is the robot stuff and he was building robots and actually, the graphic programming language isn't that bad, you can drag and drop and do stuff so he was programming robots and at nine or 10 he programmed it to actually track on the black line using the optical sensor without any of my help, which, I helped him figure out how to turn on a motor and turn off – but he actually figured out how to look, turn, look, turn find an O, stop. He figured all that out and programmed it and that robot would follow the line all the way around – that was when he was like nine or 10.

In addition to learning with his father, Craig described a peer who was a friend and learning partner.

> C: I have a friend who is very … who likes computers a lot. He goes to Bayridge, which is the school further in that direction. But he was with me in elementary school. We both loved computers and we teach each other some of the things we find out. 'Did you know you can do this?' Or, 'how do you do that?'
> I: Do you ever do projects together with him?
> C: I did for school. When we were in elementary school we did a PowerPoint, which no one else knew how to do, so it was kind of a new idea and then everyone else thought it was great. So I mean, I think we definitely teach each other how to use technology, you know. We get together sometimes and we'll just do some things. He has an Apple, he's always had an Apple and I just got an Apple recently. So some of the stuff … he was on OS9 and my computer came with OS10 on it, so I got to know OS10 and when he got OS10 on his computer he's kind of like, 'nothing is the same. It's all different.' So it's like I taught him some things and then he taught me some of the stuff that he found out which I would have never known to look for because I've never used OS9 really in depth.

Around the same time as he was beginning with robotics at home, he participated in a community center class that introduced him to HTML and software that would allow him to more easily create web sites. Soon after that, his grandfather employed him to design and build a web site that would help him promote a book he was writing. This job turned out to be a rich learning opportunity for Craig and led to encounters with service providers, opportunities to consult with his father, use of tutorials, and exploration of web sites with his grandfather.

> I: What kind of things did you learn from?
> C: More of the … how Internet providers who actually take your site, how they work and how they do things. You know, so how you have to upload the stuff, having special things

where you have to have special code to do certain things. We were working on his e-Store, like a merchant store where even though you type in your credit card number and you were emailed like whatever, you don't have to purchase, but that was all beyond me. You have to type in all the encryption codes in certain areas of the site.
I: How would you describe that learning process that you were doing on your own?
C: Well, I would sometimes go and look at what … I would look at Macromedia. They had some disk a while ago that was like stuff like how to do certain things. Kind of like an instruction manual on a CD that had some animated examples, like here is where you do this. I learned from that and modified their instruction a little bit so it would fit what I was doing. So some of the stuff they had, you know, on their CD I kind of incorporated that with my stuff. That's more of the uploading of the stuff to the server. I also learned more of how the different numbers like the server ID, your account ID in your folder, your password, stuff like that, and how they all had to be in certain places and you need to know certain ones more than others. And he (Craig's grandfather) showed me some sites and I looked at the script thing … I looked at the script thing in some of the sites he was showing me and it's kind of like sometimes it shows what software, in the code, it says designed by Macromedia, Dreamweaver, whatever version, commercial edition, whatever. So I would see that and sorts of things like the meta-tags, what they were using to catch like search engine attention. Stuff like that. So we did some research of what other people in the same business were doing.

Also around age nine, Craig became an apprentice of sorts to a videographer. Each week, Craig would observe this videographer filming his church services. He recalls being invited up to the choir loft to help one day. After that visit a three-year relationship began during which Craig learned to run each of a part multipart camera recording system and became familiar with the underlying technology and how to keep it tuned.

I: What do you do in church?
C: In church, services are filmed and distributed to people who can't come to church and also broadcast in a time slot on public television.
I: How did you get involved with doing that?
C: He came down one day and invited me up because I always kept looking up there. It's in the choir loft and I would always kind of look up there because I would see all the rows of monitors because we have like a five camera thing and they have their own little monitor in a rack. I was looking because it looked fascinating.
I: So what part of that process have you been involved with?
C: Well, there is a guy there who has a mixing board and the cameras and the sound board and all the microphones have basically a camera, switching all the cameras and then also I've done sound. I've done it all. I've learned from him because he worked at Macrovision … he works at Macrovision and the company who did a lot of the copy protection DVD stuff. They created some of the encryption stuff or the code so the computer can't copy a DVD which is fine. He would … different problems come up when you are doing video because obviously video is … especially since we are kind of an analog system even though we do use a lot of digital stuff. Some things get out of adjustment. It's kind of like an instrument, you have to tune it all the time to keep it in shape. The cameras would go off, you know, have maybe a little more move than they were supposed to. So we would constantly be fixing things and I would learn kind of how things worked, how frequencies affect the picture and how … he has little monitors … I forget the name right now, but they showed the waveform monitor and also a scope that showed color. I learned why they actually have those color bars during, before or after a television event, why they have color bars in the tone. So I learned why they have that.

His interest, signaled by watching the process of filming the service, was 'picked up' by an adult in his community who then spent time helping him learn more. It is of note that the videographer who Craig apprenticed with had other helpers and had added an extra camera, for the sole function of being a place for the newest member of the team to learn. The entire team was connected with headphones, and in an interview, the videographer reported that he never taught his helpers directly but rather gave them instructions about where to shoot and focus. He believed they learned the system by listening, observing, and enacting.

When the school purchased broadcasting equipment and the industrial technology teacher was asked to teach a course, he capitalized on Craig's skill in video production. Craig enrolled in the class but acted as an informal teaching assistant. This was not his only teaching role: he was also asked to assist in the web design class.

While there is no doubt that Craig's 'fascination' plays a huge role in the generation of learning opportunities, it is useful to catalogue the roles that various adults play in his life. His mother who described herself as 'the schlepper' and claimed to know little about technology, actually revealed that she played an important learning broker role. For example, she was the one who found a robotics club and encouraged him to sign up. In contrast to Wenger's [1998] knowledge broker who translates information and ideas among professionals from disparate communities, as a learning broker she found learning opportunities for Craig.

> I: Are there other examples of setting him up like that?
> M: Summer camps – finding out about the camps – the Stanford Camp that was ACE – that was on the news and they were showing the summer camp and I wrote it down for the next summer – that kind of a deal – when I hear things. Right now I have one at NASA – I took a little newspaper clipping of a thing they have at NASA and they are doing robotics but it is for high school kids – that is with Carnegie Mellon and NASA – they have some program together so whenever I hear of something I pretty much know what Craig will like …

His father described more direct roles as a learning partner but also reported that they shifted over time and both parents resisted the idea that they were teaching Craig. As his father put it, 'I am more of kind of a dictionary than a teacher' and described another role when he pointed him to a specific section of a book to get an overview of the C programming language.

> I: Do you remember a recent time where you sat down with him to interact with him to learn?
> F: It is all the time, it is a constant. It is not – I don't think it is like sitting down and –
> M: We don't teach him.
> F: We help him find out – it is like – for instance this C thing, he was doing all the programming for the Lego's in the Lego language and then for this school project it had to be in Interactive C, which is a little bit different than C but it is similar to C – so that was when I got the KNR book and rather than me teaching him C, which is going to be difficult, I said, 'what you really need to do to start – all you really need to do is read the first 34 pages and that describes to you how C works, then you will be able to understand the syntax and look for where the syntax is.' I will just give him the book and give him the sections that he needs to read and he will go read them and then he does it. He was having trouble with the 'while' statement and it was the way that he was – he was mixing up integers. [Integers] and long variables – I have not done C in a long time but he was mixing types up – I have been explaining to him how the types have to be consistent and what that means. I am more of kind of a dictionary than a teacher – if that makes sense.

However, the interview revealed multiple roles. In addition to pointing to resources as in the example above, Craig's father would often give him extended explanations of how something worked, such as how gears function and the implications for his robot design. He also on occasion brought him to his work to allow him to observe how things are made in a machine shop. The topics Craig identified at the end of his interview as future learning goals suggest that both informal and school-based experiences are continuing to feed the development of more specific kinds of interests for him.

> I: So if you could learn anything about computers or how to use them, what would you learn?
> C: That's tough. Probably more how they work and how to tell them to do more things. More programming-oriented, more hardware-oriented stuff like … kind of like how to create stuff like Windows or Mac … Mac and Windows copied Xerox on their GUI interfaces. It's kind of like … I want to learn kind of how they programmed that. Kind of like how that works … I like interfaces, it's kind of interesting … Or like AI stuff that people are trying to figure out. It's like you can probably get it to a certain point, but it's never going to be to the point where it probably will teach itself anything. If it does, it's a very far way away. Learning how they do that … there are a lot of ifs, ifs, ifs and probability. Just learning stuff about that.

He would like to take more classes at school, however they do not offer advanced programming. He plans to stay involved with the robotics club and to seek out other learning opportunities.

> I: And do you have plans for learning more?
> C: I want to take more classes. I want to take probably a few … I wish there was a class after this programming class, but there isn't. There is no programming 1B. So, I'll try to find somewhere else. I'll continue with the Lego stuff and probably learn more there.

Analysis

Emergence of Interest. Craig's interest in creative technologies emerged early in his development. It began at home, and his parents continually nurtured it. Because his interest is so long-standing, we have less of a sense of the specific activity that caught his attention than we do for Jamal or Stephanie. Craig recalled watching his father work on the computer and being interested in how fast and flexible the machine was. His parents too recalled this early interest and encouraged it in multiple ways such as providing him with access to camps and buying robotics kits that he could work with. They later bought him computers and software. The continual feeding of his interest with new resources, activities, and learning opportunities is best characterized as a joint accomplishment – the result of his enthusiastic response to opportunities and his family's willingness and ability to nurture this interest. Both of his parents were highly involved in what Rogoff [2003] calls 'guided participation.' The father took on a collaborative partner role and also oriented him to resources when needed. His mother did a significant amount of work as a learning broker, finding learning opportunities and encouraging his participation. She was also instrumental in helping him get to the places he needed to go to learn. As Craig got older, he took on more responsibility for projects. His parents began requesting detailed project plans, as he was continually asking them for supplies to do projects that often were not very practical.

Creation of Learning Opportunities. Mapping Craig's activities at the time of the interview reveals an extraordinarily rich learning ecology with learning opportunities distributed across multiple contexts. For the most part, the projects that Craig became involved in were jointly created or found by himself and his family. However, once in a project, Craig was able to articulate several of the self-initiated learning strategies that are listed in table 1. For example, in the context of his grandfather's web site, he reported using tutorials *(creates interactive activities)*; exploring and looking at other people's web sites as models *(explores media)*; and consulting with network providers *(builds knowledge networks).* He also consulted with his father on occasion. Though he was invited to join, his becoming a member of the video team at church might be considered an example of *creating a new project* for himself. Finally, on multiple occasions, Craig sought out structured learning opportunities at school and in the community *(seeks out structured learning)*. With respect to other text-based resources, Craig reported reading *Mac World* and *Popular Science*, and on his bedside table were books on robotics and on the programming language C, the very book that his father had referred him to *(finds text-based information)*.

Boundary Crossing and Bi-Directional Influence. Craig's interest-driven activities showed up in every life space he was asked about. He was engaged in technological fluency building at home, school, in the community, on-line, with friends, and through a job. The knowledge he gained through his church mentorship provided him with a new role at school. It is likely that this new role generated some insights that he brought back to the church context. Based on his growing expertise with video, Craig had also landed himself a job with his sister's music teacher. He taped student recitals and then created DVDs of the performances for parents. The learning of other content, such as programming languages, also resulted in knowledge that flowed between contexts. When asked if his programming in the robotics club helped in his programming class, he answered 'some of the stuff I learned actually in here helped me there and some of the stuff I learned there helped me here.' Out of the three case examples, Craig represents the learner with the longest standing interest, the most extensive learning ecology, and the most involved family. These interviews reflect the intermingling of his own interest and his family's support.

Summary and Directions for Future Research

Sociocultural and ecological theories of human development seek to conceptualize the interacting roles of culture, practices, and resources in human development. There is a complementary interest in how individuals contribute to their own development through appropriating and adapting the resources provided to them. In this paper, I have proposed that to make progress on understanding processes by which people contribute to their own development, it would be useful to conceptualize how self-initiated activities mediate learning in the short term within and across contexts. The learning ecology framework shared in this paper includes three main conjectures and affiliated empirical research strategies for extending theory and understanding of how self-initiated learning plays a role in development while also taking into account resources provided in the environment. First, the framework brings to the foreground the role of interest development. The first conjecture is that interest de-

velopment is triggered by ideational resources that are available in diverse facets of a learning ecology. Second, once interest is sparked, people utilize a variety of strategies to further their knowledge development. Third, I argue that learning activities based on interests are particularly likely to be boundary crossing and that consequently a learning ecology is best conceptualized as a dynamic entity that can be characterized by the diversity and depth of learning resources and activities.

Each of the three conjectures underlying the framework is illustrated by the learning histories of three focal learners. With respect to the first conjecture, the examples suggest that interest can develop in very different contexts: home, school, church, and in playful informal activities with friends. These examples also illustrate the importance of ideational resources for the initiation of learning activities and maintenance of engagement. Interest was tied to different kinds of resources such as an assignment to create a web site, or access to a blogging environment that easily afforded personalization through HTML coding. Relational resources in the form of friends, parents, and teachers were clearly bound up in the activities. It makes sense to understand the configurations of people, ideational resources, and activities as systems in the way that activity theory describes. We must also include the prior history of the learner and his or her sense of self. Feldman [1986] uses the term 'co-incidence' in his work on prodigies to refer to the necessary confluence between biology, local environmental forces, and longer-term cultural factors in talent emergence and recognition.

The second conjecture proposes that once interest develops, a variety of strategies might be employed to further learning. The three focal adolescents were active in structuring and extending their own learning, and used their discretionary time to learn, and thus might be called committed learners [diSessa, 2001]. Five main learning strategies were identified, including finding text-based informational sources, the creation of new informal activity contexts, exploration of media, the pursuit of formal or structured learning opportunities, and the development of knowledge networks such as mentoring relationships. In all of the cases, more than one of these strategies was used to extend learning. While more research is needed to confirm their ubiquity, the examples suggest that we could think more broadly about learning, and actively consider the interconnections and complex relations between formal learning experiences provided by schools, and the informal learning experiences that students encounter in contexts out of school. These examples also point to the importance of thinking beyond physical contexts, to consider the role of distributed learning resources such as books, magazines, and those offered through the Internet.

In the case of Jamal, his interest was sparked in school, and in the short term led to the purchasing and reading of extra books on the topic of HTML. This interest, and the end of his class, led to the initiation of a longer-term project of starting a business which then served to motivate further learning and afforded him new roles in his community as an author and creator of web sites. This shift might be considered of the kind that Beach [1999] calls a 'consequential transition' and is worthy of note because of the clear way that he is creating a context for learning for himself. It is not that Jamal's motivation was purely to advance his knowledge, for he was also thinking of his future and of the way that this work could serve as a career with economic as well as creative benefits. However, when he was a year older, he conveyed that though the business was not realized, the idea of the business was

used to organize school assignments. Many specific learning strategies like reading, contacting experts, and finding partners came out of this boundary-crossing activity. Across our three examples, we saw strategies such as exploring, examining the products of others to learn by example, contacting experts, and developing a project, reading books, completing tutorials, and deciding to take a class. Learning was distributed across activities and resources. In the literature on self-directed learning, these kinds of strategies are rarely described. This may be due to the time scale in which learning is studied. Verbal think-aloud protocols, for example, have been used to study differences between more and less effective learners. This approach yields important information on micro-genetic processes but misses the larger activity contexts that motivate strategies at a molar level (e.g., seeking out a book that might stimulate a self-explanation).

The third conjecture is that interest-driven learning activities are boundary crossing and self-sustaining. In each case, once interest was sparked, learning opportunities were capitalized on in a different context than where the interest first developed. In addition, there were fertile bi-directional flows of knowledge between contexts. In Jamal's case, he brought his business interest back into school and used it as a context to personalize his assignments in business class. Craig used the knowledge gained in his programming class to further his robotics club design work, and also used new insights into hardware and software relationships in school. His interest led him to view church as a place where he might learn more, perhaps the most compelling evidence of how an interest can serve as a lens for viewing new contexts. He was also asked to step out of his student role and become a teaching assistant in more than one course. In both of these cases, the boundary crossing was made possible by school structures that afforded flexibility in assignments or roles. Stephanie became more expert in designing web sites at school and then brought that knowledge back into her blogging site. She was also invited to help create a family web site and work on her father's emerging business web site. In each case, interest led to additional learning and to new activities and roles. Beach [1999] argues that while everyday learning events are characterized by conceptual growth and progress, consequential transitions are accompanied by shifts in identity, social position, or taking on new roles. He suggests that consequential transitions cannot be located either in individuals nor contexts, but rather are changes in their relationship: 'both person and social context contribute to a consequential transition and are recursively linked to each other.' Like Bronfenbrenner's [1979] ecological transitions, the idea of consequential transitions focuses on changing environment-person relationships and offers a conceptually useful way to think about developmental processes that take place in more intermediate time scales and have resonance for young adolescents.

As for future research, it would be of interest to use methodologies that would better allow for analysis of the micro-interactional processes that sustain learning in informal contexts. While we have numerous studies of children's conversations in the context of researcher-defined collaborative tasks, we have less of an understanding of how peer learning takes place 'in the wild,' to use Hutchins's [1995] apt phrase [though see Rogoff, 2003, for exceptions and John-Steiner, 2000, for accounts of adult collaborators]. It is likely that some of the same processes that we see in lab studies [e.g., Barron, 2003; Webb, 1989], such as observation, explanation, and joint monitoring of solutions, are common, however, we may also find processes that take place over longer time scales and that have their own unique dynamics. Certainly,

there is much to learn about how peer groups access and use the Internet as a source for models to imitate or a place to find instruction and explanation. We need to know more about the interpersonal micro-interactional processes and affective processes that support interest development; for example, the role of enthusiasm expressed by friends and family for a topic or artifact, or the excitement felt when students employ their newfound knowledge in the context of their designs or when they gain insight into a complex idea. In all three case examples, the learners reported that exploring on one's own is the way they learn the most, but it is not clear exactly how or what they are learning. What cues the desire to explore to learn, and how do episodes of exploration for learning leverage metacognition, knowledge building, persistence, and social networks? Azevedo [in press] has documented through video analysis what he calls 'personal excursions,' episodes where students depart from instructionally framed activities to engage in self-directed learning. Particularly relevant here is that his analysis points to the flexibility of the computation medium, as well as the importance of free time in supporting these excursions. More ethnographic work might help deepen our understanding of how interest emerges.

More research on learning in families is also needed. The three case examples differed substantially in their early history of technology use and sponsorship by their parents. Craig stood out in the longitudinal nature of his interest and the substantial investment his parents made in nurturing his knowledge development. We know little about the ways in which early experiences shape learning practices. For example, do children who learn via projects tend to recruit this as a learning strategy later? Understanding more about diversity in experience and perceptions of experience is critical from the perspective of equity. Though in this paper the role of self-initiated learning is emphasized, it is also clear that home resources mattered a great deal. Parents played roles as learning brokers, financiers, consultants, project partners, socializers of the value of knowledge, cheerleaders, and as pointers to other knowledge resources or as Craig's father put it serving as a 'dictionary.' Other adults were also important when they were sensitive enough to pick up on the learner's interest and then support it. There is substantial data that suggest that differences in use of computing technology occur along socioeconomic status, gender, and cultural lines [Attewell, 2001; Camp, 1997; Warschauer, 2003]. In seeking to understand individual differences in learning outcomes, researchers have not attended enough to the kinds of resources that support successful learning within and across settings. Research that helps detail resources and the role they play in learning across life spaces may help us address this gap.

Second, we know little about the *appraisal processes* that were hinted at by the interviews that seem to be important aspects of interest development. In all the interviews, but particularly in Jamal's and Stephanie's, there seemed to be a set of questions that were being taken up in the course of learning: 'How does this topic fit with how I see myself and my future?', 'Does it allow me to extend my goals and create what I want?', 'Do I like the idea of becoming the type of person that does this?' This view of interest and the examples shared highlight the need for more process accounts of interest development from an appraisal point of view. For example, what is involved when people make assessments of a domain or topics in terms of whether it matches their sense of self or values? If the domain is associated with a type of person or potential future self, does that image serve to attract or detract from the interest? How can a specific experience break down stereotypes of work and the

people that engage in it? What aspects of an experience confirm or challenge ideas about whether a domain of knowledge fits with a sense of self? What we can say from the interviews is that these three very different adolescents, coming from fairly different backgrounds, all found ways to become engaged.

The research literature on interest development has mainly grown out of psychological theories of motivation that focus on achievement orientation [Wigfield & Eccles, 2000] and personality development [Krapp, 2002]. In these theories, interest is thought to be situational or personal. Personal interest is treated mainly as an attribute of an individual and considered to be relatively stable. However, there has been renewed attention to issues of engagement by a broad range of researchers [Hickey, 1997]. In a recent volume, diSessa [2001] discusses the generative and evolving nature of interests. His insights come from reflection on his own development and how his interest in electronics emerged and shifted across time. Hidi and Renninger [2006] define four phases of interest development with the fourth phase characterized as driven internally and the earlier more dependent on other people. Cobb and Hodge [2005] contribute to this agenda with an analysis of the cultivation of interest in a mathematics classroom. Their data come from a statistics unit where they documented two phases of interest development. The first they termed 'pragmatic' and it grew from the framing of the statistics problems (e.g., the efficiency of various batteries for powering CD players), which was followed by a type of interest they called 'statistical' that developed when comparing methods of data analysis. Although the context of inquiry in Cobb and Hodge [2005] is limited to the classroom, their analysis of the shifting pattern of engagement in relation to the problems and the resources of collective and individual interest identifies important dimensions of a specific learning ecology.

These brief portraits are consistent with the idea that often the development of expertise goes hand in hand with a growing sense of one's self or identity as connected with the activities and roles this knowledge makes possible. Particularly relevant to the current paper are new ways of thinking about processes of identity development that draw on Vygotsky's [1978] and Bakhtin's [1981] notions of the role of dialogue in learning. Holland et al. [1998], for example, articulate a process of students positioning themselves within figured worlds using 'identity tools' such as artifacts or language genres. In this view, identities are always developing and are based on both personal histories and interaction with a diverse world that is populated with many voices, ideas, languages, and ideologies. An imagined future self helps motivate learning, as does the simple pleasure of creating. Interest-related identity development can be productively seen as a dynamic process that is dependent on opportunities to explore, reflect, and initiate designs with others and on their own. Although some students stumbled across activities in the context of their peer interactions that led to learning goals, for others an organized school context was critical.

Third, each of these learners used strategies consistent with the bricoleur image described by Turkle [1995], building on the concept introduced by Levi-Strauss [1966] where information is flexibly gathered and put together for new purposes. It would be interesting to know more precisely what competencies these flexible learners are developing when they engage in self-directed learning. Do the experiences lead to the skills needed to play knowledge broker roles [Tuomi-Grohn & Engeström, 2003; Wenger, 1998] or do they build capacity to find and adapt learn-

ing resources when needed? It would be useful to identify what helps people perform in unpredictable situations, a competency embedded in definitions of 'adaptive expertise' [Hatano & Inagaki, 1986; Resnick, 1987; Schwartz, Bransford, & Sears, 2005].

Finally, a fourth direction for research would evaluate the learning ecology framework as a useful design tool for educators interested in issues of equity who want to seed learning both in school and out of school, and as a conceptual tool for researchers who might want to assess interventions to examine their generativity with respect to sparking self-sustained learning. The idea that a learning ecology is itself dynamic and can be assessed suggests an alternative way to examine the success and generativity of any learning environment. Imagine an intervention designed to encourage participation of girls in technical fields. One could design different conditions that vary in the way they intend to spark interest. One could measure the amount of time spent learning about technological topics and the types of resources used to learn before the intervention and then again sometime after the intervention. The learning ecology framework would predict that in addition to knowledge gains we might see changes in learning processes and see an increase in learning events and uptake of resources across multiple contexts. To extend this idea, a novel way to evaluate the success of any classroom or community-based intervention would be to measure how often students found ways to continue learning after the classroom experience was over rather than simply measuring how much they learned during the class. This kind of measure might reflect more about the role of the intervention in interest development rather than near-term knowledge development. However, it can be argued that the development of curiosity and the nurturing of intellectual engagement are as important as the accumulation of facts. The idea of expanding how we measure the outcomes of a learning environment has recently been explored by Bransford and Schwartz [2001]. They argue that educational experiences should be assessed in terms of their potential for preparing students for future learning with resources and feedback and not just their efficiency in preparing students for solving narrow classes of problems without resources or feedback.

The reports from the young learners shared in this paper highlight the dynamic, highly social, and self-sustaining processes that are an important aspect of knowledge and identity development. They suggest that we should expect interest in learning to originate within and outside school and that adolescents have a significant role to play in sustaining their own development. As researchers interested in human development, we are in a vital position to help envision what self-sustaining learning ecologies might look like and investigate how resourcefulness might be nurtured. I would only suggest that we continue listening to those we hope to engage and invite their participation in shaping activities to come.

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