Why Computing Students Learn on Their Own: Motivation for Self-Directed Learning of Computing

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In this article, we address the question of why computing students choose to learn computing topics on their own. A better understanding of why some students choose to learn on their own may help us to motivate other students to develop this important skill. In addition, it may help in curriculum design; if we need to leave some topics out of our expanding curriculum, a good choice might be those topics that students readily learn on their own.

Based on a thematic analysis of 17 semistructured interviews, we found that computing students' motivations for self-directed learning fall into four general themes: projects, social and peer interactions, joy of learning, and fear. Under these, we describe several more specific subthemes, illustrated in the words of the students.

The project-related and social motivations are quite prominent. Although these motivations appear in the literature, they received greater emphasis from our interviewees. Perhaps most characteristic of computing is the motivation to learn to complete some project, both projects done for fun and projects required for school or work.

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1. INTRODUCTION

This article investigates computing students' motivation to do self-directed learning of computing topics as part of a larger investigation of self-directed learning in computing. We were led to this investigation for several reasons.

First, this is a phenomenon that we have observed: we have all had students who learned PHP, or Eclipse, or Linux, or some other computing topic on their own.

Second, there are students who request classes in a topic rather than teaching themselves. We have all had students ask us, "Why don't you have a course in PHP?" "Why don't you teach AJAX?" or similar questions about other topics that they might like to learn. As the field of computing grows, we often add new courses, but we cannot teach everything. A better understanding of computing students' self-directed learning may help us to choose which topics to include in our curricula, which to omit, and how to guide students to teach themselves the topics we do not include.

Third, industry places a high value on the ability to do self-directed learning. In Zander et al. [2012], we reported on an investigation of computing professionals' attitudes toward self-directed learning. All participants in that study agreed that professionals must do self-directed learning on the job, and the capacity to do self-directed learning is very important to prospective employees. Thus, it may be important for our students to develop and demonstrate this ability even before they enter the workforce.

These observations have further implications for teaching. Should we be guiding our students to begin learning on their own? And what about the students who become so fascinated with learning the latest and greatest programming languages and technologies that they neglect their formal course work? What kind of balance between self-directed and formal classroom learning is appropriate?

In this article, we address the specific question of motivation: what motivates students to learn computing topics on their own? Based on an analysis of 17 interviews with computing students with a variety of backgrounds, we propose an answer to this question, which in turn has implications for teaching and suggests directions for future research.

The structure of the article is as follows. We begin by discussing our methodology in Section 2. We then present our results, organized as stories and themes, in Section 3 and put them in the context of related work in self-directed learning in Section 4. We discuss our results in light of related work on motivation in Section 5. The generalizability of our results is addressed in Section 6, implications for teaching in Section 7, and threats to validity in Section 8. Finally, we conclude with suggestions for future work in Section 9.

2. METHODOLOGY

From 2009 to 2011, we interviewed 17 students about their self-directed learning experiences in computing. Six researchers each recruited participants who had done self-directed learning through email and personal contact. Interviews were generally conducted at the researcher's institution, but sometimes at another location, such as the participant's workplace or a coffee shop, if more convenient for the participant. Interviews were generally between 45 minutes and an hour and were recorded and transcribed. All interviews complied with the relevant human subjects' requirements and had the appropriate approval.

We were interested in understanding how the phenomenon of self-directed learning is seen and understood by different people, in different settings, and at different times. We thus did a maximum variation sampling in the sense that the sample varies with respect to age (approximately between 20 and 40 years old), level of educational (from undergraduate to graduate), work experience (from very little to significant industry experience), gender, and nationality. Most of them discussed individual learning

Table I. Brief Descriptions of Participants

Pseudonym	Gender	Age	Description
Anders	male	20s	undergraduate
Cedric	male	20s	undergraduate
George	male	20s	undergraduate
Quentin	male	20s	undergraduate
Tanner	male	20s	undergraduate
Ivan	male	20s	undergraduate
Ryan	male	30s	undergraduate
Sebastian	male	30s	undergraduate
Fred	male	30s	part-time undergraduate, significant industry experience
Kyle	male	30s	graduate student
Larry	male	20s	graduate student
Nathan	male	30s	graduate student
Oscar	male	20s	part-time undergraduate, significant industry experience
Danielle	female	30s	undergraduate, significant industry experience
Brigit	female	20s	graduate student
Molly	female	over 40	graduate student, significant industry experience
Penelope	female	over 40	graduate student, significant industry experience

Note: Unless otherwise stated, all students are full-time in a computing program. Significant industry experience means more than 2 years full-time.

experiences, but four (Quentin, Ryan, Sebastian, and Tanner) reported on a group independent study (a course for credit, but with minimal guidance from the instructor) where they worked together to learn artificial intelligence.

Table I gives a brief description of each of the participants, along with pseudonyms that we will use to refer to the participants in the remainder of the article. We include as much information as we can consistent with protecting the participants' anonymity. Of the 17 people interviewed, 4 were women, including 2 undergraduate and 2 graduate students. Most were in their 20s and 30s. There was a continuum from undergraduates with no industry experience to students (undergraduate and graduate) with some industry experience to students with 10 or more years of industry experience. For purposes of anonymity, we have not specified the country for each participant, but 3 participants were at Swedish institutions, 2 were in the United Kingdom, and the rest were in the United States. Our solicitation for participants explicitly asked for people who had done self-directed learning.

These interviews enable us to describe both a wide variety of experiences of self-directed learning and patterns common across the variation. Such a sample puts us in a position to say that the motivations we find do exist; their frequency within these subpopulations (or overall) is a matter for a further (and more quantitative) study.

Our interview script, given in the appendix, is theory based, inspired by Knowles's widely used definition of self-directed learning:

> [A] process in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes. [Knowles 1975, p. 18].

There is not a complete one-to-one mapping between our script and Knowles's definition, but there is a close connection, as shown in Table II.

The questions about motivation, "Why did you choose to learn this?" and "Was there a point where you became stuck or discouraged? Why did you persist?" elicited a

Table II. Correspondences between Knowles's Definition of Self-Directed Learning and Our Interview Script

Knowles	Script
A process in which individuals take the initiative	Why did you choose to learn this?
With or without the help of others	Were there other people involved? Were you working in a group?
Identifying human and material resources for learning	How much did you use the Internet? How do you know your source is reliable?
Choosing and implementing appropriate learning strategies	How did you learn it? Was there a point where you became stuck or discouraged? Why did you persist?
Evaluating learning outcomes	How could you tell that you had learned it?

wide variety of responses, and aspects of motivation were discussed throughout the interviews. The responses that touch on motivation form the basis of this article.

To examine motivation in more detail, we use thematic analysis as our methodology. Braun and Clarke [2006, p. 79] describe thematic analysis as a "method for identifying, analysing and reporting patterns (themes) within data." They stress that because this method is consistent with a variety of theoretical approaches, it is essential for researchers to be clear about their philosophical assumptions and the way in which their analysis is done.

Our thematic analysis takes what Braun and Clarke would describe as a contextualist approach, between the extreme realist position, where the language of our interviews would be assumed to reflect reality, and the extreme constructionist position, where the language of the interviews is treated as the "effect of a range of discourses operating within society" [Braun and Clarke 2006, p. 81]. We assume that the language of the interviews generally reflects reality, but it still can be affected by the way the interviewee chooses to tell his or her story and the broader social context.

Braun and Clarke use the terminology *data corpus* (all collected data), *data set* (the subset of the corpus used in a particular analysis), *data items* (the units that make up the dataset), and *data extract* ("an individual coded chunk of data" extracted from a data item [Braun and Clarke 2006, p. 79]). In these terms, the 17 interview transcripts are our dataset. The entire data corpus (so far) includes these interviews, plus 88 essays where students were asked to "describe an experience of informal learning in Computer Science." The data items are the individual interview transcripts. The data extracts are coded excerpts from the interview transcripts. The data extracts that we focus on in this article are those related to motivation.

Thematic analysis is consistent with both top-down and bottom-up approaches. We have taken a bottom-up, data-driven approach, reading through the data and looking for themes before comparing these themes with the relevant theories of motivation.

Specifically, our data analysis followed the steps outlined by Braun and Clarke [2006, p. 87], which are presented next.

Familiarize yourselves with the data. Initially, the interviews were read and re-read by all researchers.

Generate initial codes. We tagged three interviews as a group, during a face-to-face meeting. We then split up and, working in pairs, tagged the remaining interviews in relation to the questions in the script, creating new tags as needed. The tags were added to ATLAS TI (a qualitative data analysis software tool), and terms were normalized. This was an iterative process until all interviews were tagged, which resulted in 188 normalized tags. At least two researchers looked at every interview. After it became clear that motivation was an important topic, we re-examined all interviews looking for aspects of motivation. We ultimately ended up with 27 different motivation tags.

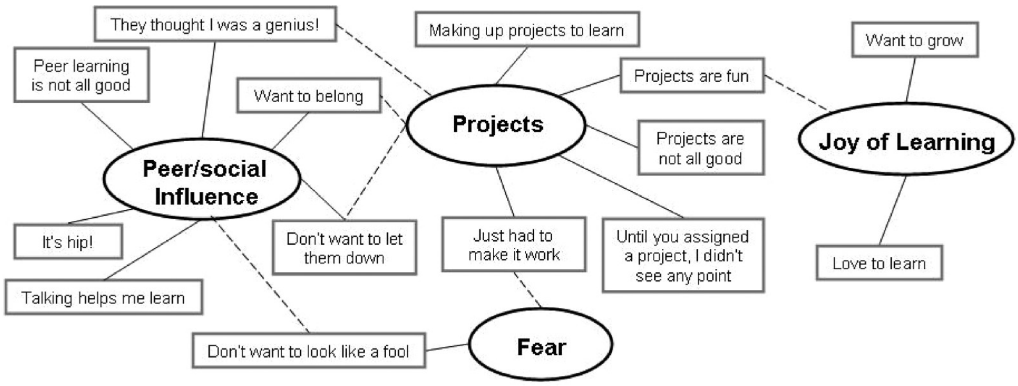

Fig. 1. A map of the themes and subthemes. This graph shows the connections between the different themes (ovals) and subthemes (rectangles) that emerged from the data analysis. Some subthemes can be abstracted into more than one theme; solid lines correspond to placement in Section 3, but both line types indicate a relationship.

Search for themes, review themes, define and name themes, and generate thematic map. In these steps, one important decision is whether to look only for themes that are explicit in the data or to look more deeply for "latent" themes [Braun and Clarke 2006, p. 84]. Our thematic analysis is at the latent level, going beyond the semantic content of the data, to identify the underlying ideas and assumptions that shape the surface meaning of the data.

The identification of the themes was a common effort among the researchers. After agreeing on the motivation tags, we re-read all of the quotations with those tags, reviewed them in context, discussed them in relation to emerging themes, and grouped them into themes and related subthemes in an iterative process. In this process, new themes emerged, whereas others fused until consensus was reached among all researchers. The themes and subthemes included in that consensus are discussed in detail in the following section.

3. THEMES

Four main themes emerged from our analysis of motivations: projects as a motivation or support for learning, social influences from peers or others, the joy of learning, and fear (of looking foolish or failing). Each of the main themes is accompanied by a number of subthemes, which we illustrate with study participants' stories. The identified themes and subthemes are shown graphically as a thematic map [Braun and Clarke 2006] in Figure 1. Unlike Braun and Clarke, we have some subthemes that can be abstracted to more than one theme; in those cases, we use both dashed and solid lines, using the solid line between the theme and subtheme to indicate the most closely related abstraction and report the subtheme under that theme in this section.

3.1. Theme 1: Projects

The first theme involved learning things because they are related to some project. Sometimes the project came first—either because the student chose to do it or because it was assigned for a course or by an employer. To our surprise, sometimes the project was secondary. Students who wanted to learn some topic would deliberately find or create a project where they could apply that topic.

Despite the motivational value and importance of projects, there are disadvantages to project-based learning. In Subtheme 5, students discussed those disadvantages.

As shown in Figure 1, the Projects theme is central—it has links to and overlaps with each of the other themes. Three of the subthemes of Projects are also subthemes of Theme 2 (Peer/Social Influence)—not surprising, since much of the project work in computing is done in teams. One of the subthemes of Projects ("I just had to make it work!") is also a subtheme of Theme 4 (Fear), and another (Projects for Fun) is shared with Theme 3 (Joy of Learning).

3.1.1. Subtheme 1: I Just Had to Make It Work. Danielle had her first real programming experience on the job, before she had any formal training in computing. She was assigned to develop a message board so that her group could communicate more efficiently on the company intranet. Although she did not know any programming, she downloaded a Perl script from the Internet and customized it so it worked. To make the project work, she taught herself Perl. "[O]n the job I needed to get things done . . . I just had to make it work." Reflecting on this experience, she noted, "I need to solve problems . . . it's just what I do."

Nathan taught himself PHP because he needed a Web interface for a class project. Often students report learning material on their own to make an assigned project successful, either at work or at school.

3.1.2. Subtheme 2: Projects for Fun. Anders is a college student who likes to program as a hobby. He had a flight simulator program that involved downloading maps, sometimes as many as a hundred at a time, and learned how to use bash scripting to speed up this process. Ivan is an undergraduate who taught himself to program at 12 or 13 years of age to customize an online game that he enjoyed. Recently, he saw something about gesture recognition on television, so he set up a webcam and worked on that project for awhile. Oscar says, "All the time I have periodic projects. I have different projects I start on my own just because I want to program them, and I think they're interesting and fun."

3.1.3. Subtheme 3: Making Up Projects so I Can Learn. Ivan is a university student. He makes up projects for himself that are related to the material being covered in class, because he finds that it helps him to understand the material better. For example, when he began studying Java, he wrote a game and later taught himself graphical programming when the instructor was covering text-based I/O.

3.1.4. Subtheme 4: Until You Assigned a Project, I Didn't See Any Point. Oscar took a class in object-oriented programming and found that the early small examples were not motivating. "[U]ntil you mentioned that we were making Tetris at the end of the year, I didn't see any real need to make the little applications."

Quentin, part of the artificial intelligence independent study group, learned the best by writing code for some of the problems in the book, but they did not have a project of any size on which they were working. The material became less interesting to him as time went on, and there were no exams to provide external motivation.

In contrast, in an earlier learning experience, he was extremely motivated. During one summer vacation, he had some time and wrote a program that would draw 3D triangles on the screen. He then used it as the basis for a 3D maze, a 3D Space Invaders game, and a 3D graphing program. Even though he got stuck sometimes, and none of what he did was required for work or for school, he persisted for more than a year. The project itself is what kept him going. "[O]nce I started, you know, I kinda wanted to finish it." On reflection, he thinks that having a project as "the goal to go for" might have made all the difference to his artificial intelligence study group.

3.1.5. Subtheme 5: Projects Are Not All Good. Nathan taught himself PHP for a class project. He had a very specific task that he needed to accomplish, so he surfed the Web for examples and modified those to make his program work. Later, he used PHP for a second, larger project and found that because his earlier learning had been so focused, it was also quite limited. He reflects that if you just want to get a project to work, then copying examples from the Web is effective, but if you "really want to learn," you should get a book and learn the topic systematically.

3.2. Theme 2: Peer and Social Influences

Another motivation theme involved interactions with and responses from other people. This theme is described by the students in relation to others: groups that they want to be part of, or other people who respond to their efforts, or their responses to what others do or say. The subthemes reflect these descriptions: the first two have to do with the individual performing to meet group expectations; the next two have to do with being influenced by others, either through their approval or enthusiasm; and the last two have to do with personal reflection on how the individual responds to others while learning. Subtheme 14 (shown later) is also a subtheme here, as it involves fear of group disapproval.

3.2.1. Subtheme 6: I Want to Belong. Most of George's friends were computer geeks, and they often talked about things they had created. This inspired George to create something himself. A friend recommended that he try Turbo Pascal. As a result, he started to learn about numbers, input, and output in the language, mainly using Web resources to find information. He did this for a while and ended up writing a simple computer game. After this, he moved on to PHP and started to write a Web-based online game that was a bit harder. When he needed help during this process, he got support from his new online friends. At this point, he somewhat knew how to program, but he wanted to know more about how things work under the hood, and that is why he finally started at the university.

Penelope, a graduate student, described a past situation when she had been new at a programmer job and was supposed to develop a piece of software that was an integrated part of a big system of both hardware and software. She needed to understand how all parts in the system worked together to make her part work, but at the time she did not know anything about digital or analog design. To learn about digital hardware and every other aspect of the system, she informally apprenticed herself to different people in her lab. She became skilled in reading circuit diagrams and debugging other people's designs, and digital design soon became part of her job. She developed a comprehensive understanding of the system and with that understanding, together with her analytical skills, became a highly appreciated trouble shooter.

3.2.2. Subtheme 7: I Don't Want to Let Them Down. Ryan talks about how he learns because he does not want to disappoint his peers. He discusses how social pressure in a group of students can stimulate students to learn a topic thoroughly: "So we all know each other, we all know the work that we put out, and there was definitely peer pressure to do well and to understand things, and I think that that was definitely a major factor in pushing ourselves." The students planned to present different sections of the material to each other. This stimulated them to learn their own part well so that they would be able to coherently present the topic to their peers. As Sebastian explains: "I'm going to have to present this to my fellow classmates, and so I want to do a better job."

Cedric did a summer research job where he had to learn genome sequencing packages on his own. He had little help from others, and the documentation was sparse. He "was definitely stuck and discouraged the first two and a half weeks." Although he was paid to do the job, he emphasizes that it was the feeling of "obligation to do it" that gave him the motivation to carry out the project. He was "obviously not going to give up, because you don't want to disappoint the people [who] are seeking some kind of output from you."

Oscar works together with a friend who is starting a new company, and it seems that both the social commitment and the enterprise itself are motivating: "I'm actually part of my friend's [creation of] a startup company; I'm working on it with him, and I learn a lot of what I do because of that."

3.2.3. Subtheme 8: They Thought I Was a Genius! As described under Subtheme 1, Danielle was assigned to develop an intranet message board at work. Although she did not know any programming, she downloaded a Perl script from the Internet and customized it so that it worked. She "had no idea what this program was, and when [she] got it running, everybody thought [she] was like some programming genius," and she believed that she did not "even know what [she was] doing;" she could not "even believe it works." Because of this, she was given more Perl projects, eventually "got a job running the intranet instead of just doing projects and then learning more, and from there it grew." Danielle felt like an imposter, because her colleagues' evaluation of her skill was greater than her own. This made her uncomfortable, but at the same time, she was proud of getting the program to work, glad of the opportunity to do more projects and additional self-directed learning, and proud of her success on those later projects as well.

3.2.4. Subtheme 9: It's Hip! Nathan learned PHP because he "saw PHP was hip at that moment, so [he] thought, okay, well, let me learn PHP." Kyle decided to learn Python because a friend of his kept saying, "Oh, Python's great, Python's great." He "chose Python because, one, it was fascinating to learn, it was new, and there was a whole lot of resources available free."

3.2.5. Subtheme 10: Talking Helps Me Learn. Ryan explains how peer interaction in the artificial intelligence independent study group pushed him to learn in depth, that the students learned from the presentations to each other, but that it was not just his own presentation, "but it was also being able to give good input on [the other students'] presentations as well, and hold a conversation at a high level." He goes on to say how it "just doesn't work," that "you can't come in [to the discussion] and start reciting facts that you memorized."

Sebastian discussed how other students' presentations triggered interest in learning unfamiliar topics: "When your classmate comes in and shows you all the stuff that he learned in his experiences with it, you look at it and you're like hey, I'm—you get a little bit more excited."

3.2.6. Subtheme 11: Peer Learning Is Not All Good. Quentin, a self-described "loner" when learning, worked with other students in the artificial intelligence independent study group. He had mixed feelings about learning in social contexts. He echoes Subthemes 7 and 10, agreeing that he was motivated by the desire not to let his peers down and that he could solve problems in the group that he would not have been able to solve on his own. On the other hand, the lack of deadlines sometimes made him feel unmotivated.

Tanner, a member of the artificial intelligence independent study group, found the discussions to be long winded (in contrast to Subtheme 10) rather than helpful. Tanner believes he would have learned better in a traditional class, or perhaps on an individual project, and that you should not expect that people will do their part of the job. He would consider working with the same group of people again, because they settled into a way to work together, but he thinks that if he "were just given another group, or worse, a random group of peers, [he] would probably not be interested in doing it again."

A long time before he became a university student, Ivan started to play an online role-playing game with a friend. After a while, he realized that you could "mess around" with it and discovered that a group of people were developing new game features. Ivan got involved and wrote some 4,000 lines of code. Other people motivated him to do the work, but when it comes to learning things in a group, Ivan says: “No it probably is more by myself, but I think that is just because of the way I learn things. I find things much easier to digest and understand if I can just sit there on my own with no distractions and take my own time, . . .”

3.3. Theme 3: Joy of Learning

This theme involves learning independent of any immediate need to know. It includes learning by those who simply like to learn things, as well as learning things that will help the learner in the future by increasing his or her overall knowledge and competence. This theme also includes Subtheme 2, in which projects are chosen for fun.

3.3.1. Subtheme 12: I Love to Learn. Tanner exemplifies the learner who learns for the joy of it. As a child, he learned to read by paging through an encyclopedia. He has always been “the kind of person who loves to learn new things,” which brings him great satisfaction. He has a “fairly sizable library of computer books” and gets a lot of joy out of being prepared to discuss any topic. He knows that it is “impossible to be knowledgeable in every aspect of computer science,” but likes “to at least understand everything to a degree that [he] can appreciate it and not be confused by it.” He digs into material for its own sake.

Oscar shows disdain when observing others doing something for the wrong reason: “It’s not for the passion of doing it anymore.” George likes challenging problems, “like[s] when it is very hard,” and is “happy” after the problem is solved.

3.3.2. Subtheme 13: I Want to Grow. Related to a general love of learning is the desire to improve one’s skills. As Oscar puts it: “Because if you don’t know, it’s trying to get to the top of the tree without climbing the trunk.” Oscar taught himself C over winter break “purely out of the desire that C is the basis of most, if not all, common systems.” Fred also wants to keep up on new topics and believes that is rare: “Out of a 50-person IT shop, you might catch 4 or 5 who have any interest whatsoever in exploring the field.” He tries “to take some part of each workday and put it towards reading.”

3.4. Theme 4: Fear

Finally, both Theme 1 Projects and Theme 2 Social/Peer Influences have subthemes related to fear. Subtheme 1, “I just had to make it work” (discussed earlier) includes an element of fear—fear of failure in an assigned task. Subtheme 14, “Look like a fool,” involves fear of ignorance relative to their peers or other people. The descriptions of these subthemes were emotionally charged, using loaded terms like “scared,” “stupid,” and “intimidated.”

3.4.1. Subtheme 14: I Was Afraid I’d Look Like a Fool. Molly, a graduate student, was assigned to teach an advanced Java course and had to teach herself the material. She was afraid of “making a fool of herself in front of the students,” especially because some of the students had used some of these techniques. To cope, she worked through the text multiple times, then developed a detailed syllabus, then went through the material again before starting the course.

Ryan and Tanner, reporting on their experiences in the artificial intelligence independent study, both wanted to look good in front of the other group members. Tanner commented that he would have been embarrassed to present his chosen topic to his peers unless he fully understood it. Ryan was sure that he would not have worked so hard without this kind of “credible threat that keeps [him] going.”

4. RELATED WORK: INFORMAL AND SELF-DIRECTED LEARNING

Informal or *self-directed learning* is used as an umbrella term for several different kinds of learning. In McCartney et al. [2010], we provide a background on informal learning in general and in the context of computing. In the context of self-directed learning for computing, Schugurensky's taxonomy and Knowles's definition most closely match what we see.

Knowles [1975] described the multipart process of self-directed learning that we used to develop our interview script. This process was based on his experiences as an adult educator, and it puts a good deal of emphasis on individual initiative and control: the learner chooses what and how to learn, and takes responsibility. This particular definition is widely quoted and makes the different parts of learning explicit: diagnosing the need, setting goals, identifying resources, implementing strategies, and evaluating the outcomes. Schugurensky [2000] developed a more general taxonomy of informal learning based on intentionality (Is learning done on purpose?) and awareness (Is the learner aware that he or she is learning something at the time?) and describes three kinds of informal learning: self-directed (intentional and aware), incidental (not intentional and aware), and socialization (neither intentional nor aware). Schugurensky's intentional and aware self-directed informal learning is consistent with (although simpler than) Knowles's definition. Given that our interviews were based on Knowles's definition, we did not expect to find Schugurensky's other kinds of informal learning.

In the computing education community, the work most closely related to this study is the work of Dorn and Guzdial [2006, 2010], who surveyed end-user programmers, few of whom had any formal computing education, about their knowledge of scripting and related computing topics. Our area of interest is different in that we seek to study the self-directed learning of computing by those *with* formal training in the subject.

Litzinger et al. [2005] measured the readiness for self-directed learning among engineering students using Guglielmo's self-directed learning readiness scale (SDLRS), a validated instrument for measuring the readiness of (or preference for) self-directed learning. They found that the SDLRS scores were not correlated with grades or semester standing, but the scores increased for students who took a course using problem-based learning (based on pre- and post-tests using the SDLRS instrument). Using a different scale (PRO-SDLS), Boyer et al. [2008] could show positive results from introducing elements of self-directed learning in programming classes. These papers only examined readiness for self-directed learning, not the self-directed learning experience of the students.

In McCartney et al. [2010], we reported on a preliminary study of informal learning that used student essays rather than interviews as its data source. Its main observation was that often students' informal learning experiences were related to project work. In Boustedt et al. [2011], we reported on students' perceptions of the differences between formal and informal learning, based on essays, interviews, and a classroom brainstorming exercise. To describe our work more precisely, we have now elected to call the activity that we are examining in this study "self-directed" learning, in line with the definition from Knowles. In Zander et al. [2012], we reported on an investigation of computing professionals' attitudes toward self-directed learning. All participants in that study agreed that the capacity for self-directed learning was very important to prospective employees. They found their own self-directed learning to be a source of enjoyment and pride, but also sometimes a stressful never-ending task.

Nenniger [1999] presents a "two-shell" model that describes the role of motivation in self-directed learning. His "outer shell" of motivations is composed of learning needs, which can be partitioned into task-related contentual interest (what the learner wants to learn) and procedural interest (what sorts of learning strategies might the user bring to bear). His "inner shell" is composed of the application of strategies that result in learning. These shells affect each other: the outer shell (motivation) drives the inner shell (the application of strategies while learning), and evaluation of the inner-shell experiences changes the outer-shell motivations for doing self-directed learning in the future.

5. RELATED WORK: PSYCHOLOGY AND EDUCATION

Aspects of motivation found in our data are consistent with those found in the education and psychology literature. In this section, we look at several aspects and compare our results to the appropriate literature.

5.1. Intrinsic and Extrinsic Motivation

Theories of motivation have a long history in psychology and have been applied to education since at least the 1930s. Svinicki [1999] reports a progression in the development of theories of educational motivation that mirrors the development of motivation theories in psychology, from behavioralist models of reward and punishment through many sorts of cognitive models with trends toward increased learner autonomy and control.

Under the cognitive approach, several researchers have emphasized the differences between intrinsic and extrinsic motivation: intrinsic motivation is driven by the task itself because it is interesting or satisfying, and extrinsic motivation is provided by others through reward or punishment [Sansone and Harackiewicz 2000]. Intrinsic motivation has been found to be more effective. Work in the 1970s found that adding a reward structure to a task can reduce its intrinsic motivation, leading researchers to closely examine reward structures and their effects [Sansone and Harackiewicz 2000].

Those students who are motivated by joy of learning (Subtheme 12), or by the enjoyment found in completing a project (Subthemes 2 and 4), have intrinsic motivations. Other motivations, such as fear of looking like a fool (Subtheme 14), not wanting to let other people down (Subtheme 7), and the desire to learn what everyone else is learning (Subtheme 9), are clearly extrinsic.

5.2. Autonomy

The main difference between intrinsic and extrinsic motivation is autonomy: do I choose what I want to do or what someone else wants me to do? Ryan and Deci [2000], in their self-determination theory, view autonomy as a continuum and refine extrinsic motivations accordingly. From most to least autonomous, they list intrinsic motivation, followed by four types of extrinsic motivation: integrated regulation, where the person's goals and values are coherent with those of the external influence; identified regulation, where the person recognizes the importance of the external influence's goals and values; introjected regulation, where the person's sense of self-worth is contingent on performing the task; and finally, external regulation, where the behavior is driven by rewards and punishment.

Perhaps because we are examining self-directed learning, most of our themes involve examples where the learners have at least some autonomy. Mastery goals, which are fully autonomous, are illustrated by Subtheme 13, "I want to grow." Subtheme 9, "It's hip," is an example of integrated regulation: here, the learner buys into others' estimate of the value of learning a particular topic. Subtheme 7, "Don't want to let them down," could be an intrinsic motivation if keeping promises is a deeply rooted part of your character; here, it seems to be primarily integrated or identified regulation, as the focus is on doing what "they" want. There are examples of introjected regulation, such as fear of looking like a fool (mentioned earlier) or pleasure when others think you have done well (Subtheme 8).

Autonomy per se is not found in our data as a motivation for self-directed learning. When students compare self-directed and formal learning, however, they cite autonomy as a desirable aspect of self-directed learning [Boustedt et al. 2011].

5.3. Motivation and Volition

Unlike most of the motivation researchers discussed here, Corno [1993] separates the process of deciding to do a task and committing to a goal from those things that take place after committing to a goal. She refers to motivation as taking place before commitment and volition as the things that keep the person going after commitment, and calls for research that specifically looks at volition, pointing out that the challenges faced are different once the work has commenced.

The distinction between motivation and volition made by Corno [1993] is illustrated in our data by Subtheme 1, "I just had to make it work." The focus of this subtheme was the interviewees' persistence rather than their initial decision to accept a task (which had been assigned to them). In Subtheme 4, Quentin contrasted two situations, one where his volition waned as time went on and one where his volition was sustained over a long period of time. Both of these subthemes are related to projects, which require the student to stay motivated over a long period of time.

5.4. Social Aspects of Motivation

Most of the focus in the work cited earlier is on the individual, but other research has examined social influences on motivation. In a paper that builds on the self-determination theory, Reis et al. [2000] claim that autonomy, competence (mastery), and relatedness (connections to other people) are basic psychological needs affecting well-being. Wentzel [1999] argues for a model of motivation in schools that includes social motivations as well as (traditional) task motivations, and presents different ways in which these could interact. She discusses the effects of interactions with both peers and adults (parents and teachers) on student motivation.

In a popular book, Pink [2009] surveys the work on motivation. His summary is consistent with much of the theory presented earlier, particularly the self-determination theory. Although Pink's discussion of extrinsic motivation is somewhat less nuanced than those that we have described, he provides a more detailed discussion of intrinsic motivation, breaking it down into three parts: autonomy, mastery, and purpose. These three categories are similar to the three basic psychological needs described by Reis et al. [2000] Where Reis et al. have relatedness, however, Pink talks about "purpose," defined as a sense of being part of something larger and longer lasting than yourself.

Overall, our results illustrate the relative importance of social aspects of motivation, reflected in the large number of themes related to peer and social influences (Theme 2). This emphasis differs from the individual focus of much of the related motivation literature and seems to contradict the cliché of computer scientists as socially oblivious.

We did not see "purpose" as described by Pink [2009] in our data. However, if we sought out additional interviewees, we might find examples of these motivations. Students are motivated by competitive programming contests [Burguillo 2010] and also by humanitarian open-source projects [Hislop et al. 2009], both of which might require self-directed learning.

5.5. Projects

Our results identify the importance of building projects, both as a motivation for learning (when the learning follows the project) and as support for learning (when the learning goal comes first and a project is selected to deepen that learning). Blumenfeld et al. [1991], discussing the use of project-based learning in classrooms, consider student interest and perceived value as factors that can affect student project motivation. They report that these factors can be increased by (among other things) having the projects result in “authentic” artifacts, and increasing the amounts of student choice and control.

Projects discussed by our subjects involved developing something tangible (usually software), and the learning activities were described by the students as under their own control. Helle et al. [2007] ran an experiment that examined the motivation of information systems students in the context of a 7-month project course in comparison with comparable computer science students who were not involved in a project course. Examining the students before and after the project, they found that the project students’ intrinsic study motivation increased significantly, whereas the comparison group’s motivation did not.

In a literature review on project-based learning in higher education, Helle et al. [2006] found, among other things, that it is important that educators provide students with “a *rich set of resources* (or scaffolds) and *multiple opportunities for assessment and revision*” (p. 303, italics in original). Our data are different from the studies reported by Helle et al. in that the projects our students talk about are often initiated by themselves, not by teachers. Our students have thus not been scaffolded with resources, and they did not get the opportunity to have their knowledge assessed by experts. Still, students often use projects as a way to learn and find it motivating.

In Boustedt et al. [2011], we report on students’ perceived differences between formal and informal learning. In line with Helle et al., we found that “informal learning can be difficult for the learner to assess—how can a learner know when enough is learned?” and further that students discuss problems with finding “relevant resources and judging their credibility, particularly on the Internet where information is not filtered, maybe not pre-organized, and might be outdated and inaccurate.” We then suggest that students, in formal settings, should be encouraged to reflect on questions like “How will I assess my progress, and how will I know that I am done?” and “What resources are available, and which should I use?” In addition to what Helle et al. report from previous research that students need scaffolding and formal assessment, we suggest that formal education should also prepare students to find resources on their own and assess their own progress, which can prepare them for future, project-based work.

5.6. Motivation, Goals, and Self-Esteem

Some researchers concentrate on the relationship between motivation and goals. Barron and Harackiewicz [2000] distinguish different kinds of motivation based on *mastery goals*, in which someone is trying to improve skills in an absolute sense, and *performance goals*, in which someone is trying to improve their skills relative to others. Grant and Dweck [2003] further refined these goals and found that learning goals (mastery goals) and performance goals with an absolute measure have a positive effect on motivation, normative performance goals (performance goals with a relative measure, as earlier) have negative effects on motivation, and ability-validation performance goals (those that verify the learner’s abilities in an area) can have positive effects on motivation when things go well but negative effects when the learner faces “challenges, setbacks, or failure” [Grant and Dweck 2003, p. 542]. This last item is consistent with Dweck’s self-theory work [Dweck 2008], where motivation and achievement are tied to students’ beliefs about whether their abilities are fixed or can be improved. Crocker et al. [2010] examine the effects of self-esteem on motivation, specifically the way in which self-esteem that is contingent on a particular domain, such as academic performance, can reduce motivation in that domain.

We see mastery goals in our themes, notably in the “Want to grow” and “Making up projects to learn” subthemes. Although we saw self-esteem aspects in the Fear theme, we did not see the negative effects on motivation. We saw something like the normative performance goals described by Barron and Harackiewicz [2000] and Grant and Dweck

[2003] in "Want to belong": both George and Penelope sought to develop skills that they perceived other members of their group already had.

6. GENERALIZING THESE RESULTS

The value of our results to others depends in part on the degree to which they can be generalized beyond our pool of interviewees. We support this generalization using the notion of analytic generalization of Yin [2014], by which generalization is done based on a theory rather than observations from a representative sample. The theory we use is the model presented in Section 3: the various themes related to motivation for self-directed learning. Our data support that theory, which in turn can be used to describe motivation for other populations. Consistent with our results, we would expect projects and social interactions to be strong motivators of self-directed learning for computing students in many contexts, certainly those similar to university-level programs in the United States and northern Europe.

The related work in Section 5 provides another kind of theoretical support for generalizing this work. The kinds of motivations seen in our data are consistent with other published theories of motivation that were developed from other populations, suggesting their more general applicability.

Finally, our own previous work with students provides some triangulation. McCartney et al. [2010], which was based on less rich data (student essays), identified some of the same motivations: Subthemes 1 ("I just had to make it work"), Subtheme 3 ("Making up projects to learn"), and Subtheme 13 ("I want to grow"). Zander et al. [2012], which was based on interviews with industry professionals, also showed a good deal of project focus but less about motivation to do self-directed learning, as there was near-universal agreement that self-directed learning was a necessary and routine part of their jobs.

7. IMPLICATIONS FOR TEACHING

Three things follow from our work. First, it is good for students to practice self-directed learning, as they will need it when they join the workforce, both to complete projects that they have been assigned and to keep their skills current. Some students, as noted in Subtheme 13, "I want to grow," are aware of the importance of learning on their own as a way of continuing to improve their skills. Some students have already done SDL in connection with projects. We can make sure that they are all aware of SDL's importance for their professional lives by making a point of discussing it in the classroom. We should also give them scaffolded opportunities to practice SDL, where the students learn a topic on their own but as a requirement for a course. As early as data structures, for example, students might be required to learn and use a second IDE (perhaps Eclipse, if they began with BlueJ).

Second, the students we interviewed identified project work and social interactions as things that motivated them to do SDL. In a programming languages course, for example, we might ask the students to learn a new language on their own, writing a brief manual and some simple programs during the class. In a project course, we can require students to learn some new language or technology as part of their project. This will leverage the project-related motivations for learning. Social motivations will also come into play if the students are working in teams or presenting their work to each other.

How would the understanding of motivation that we present here help with such interventions? Here are some possibilities:

—*Projects*. Suppose a student has told you that she wants to learn PHP. Knowing the relationship between projects and SDL might lead you to suggest that she pick a simple project and use it to help her learn.

—*Want to grow*. For the students who do not think they need to do SDL yet, state explicitly that this is a valuable skill and part of being a software professional.
—*Fear*. Explain to the students that it is natural to feel that everyone knows what they are doing but them, and that being able to identify and learn what you need to know is both a necessary survival skill in many jobs and also a good way of coping with that fear.

Finally, SDL provides a mechanism for students to learn. We do not need to add every hot programming language or new technology to the curriculum. Students are highly motivated to learn those topics. Instead, we can focus on giving them the foundation to learn on their own. Experience with two different language paradigms, for example, and a solid understanding of programming language design will put them in a position to learn a new language on their own.

It should be remembered, however, that some students may lack the maturity or experience that would allow them to effectively learn on their own. Grow [1991] presents a four-stage model of student development, with learner stages described as dependent, interested, involved, and self-directed; each of these stages responds best to a certain teaching style: authority/expert, motivator, facilitator, and delegator, respectively. He suggests that courses within a curriculum (and even individual classes) can use a mix of these teaching styles, increasing the proportion of higher-level approaches as the students become increasingly independent, to help the students develop through these stages. The two-shell model of Nenninger [1999] would predict that students successfully applying self-directed learning would be more likely to use it in the future.

8. THREATS TO VALIDITY

There are some factors that should be considered when trying to generalize these results.

First, the selection process for interviewees was biased toward students who “had learned something on their own,” excluding students who had not done self-directed learning. This may have had a secondary effect, which was to discourage interviewees who had negative self-directed learning experiences, as they may have been less inclined to discuss those experiences.

Second, the interviewees tended to be mature: just over half of the students were either in graduate school or had significant industrial experience. Had we studied first-year students, we might have seen differences due to maturity or experience.

Third, although we interviewed students from three countries, they were all from either northern Europe or from the northeastern or northwestern United States. These results, therefore, may not apply in other geographic regions and cultures. That being said, some of the students came from other countries (India, Poland, Lebanon, and Canada) or participated in online communities where their “friends” were from all over the world, so they may reflect broader cultural influences.

Finally, the use of analytic generalization presupposes that the analysis and theory formation were carefully and competently done. The researchers on this project have a good deal of experience working together, as well as experience working in the area of self-directed learning. Additionally, as noted in Section 6, both the motivation literature and previous results are consistent with the results seen here.

9. CONCLUSIONS AND FUTURE WORK

This article reports on a study of computing students’ motivation to perform self-directed learning of computing topics. Given a rapidly changing field, the need for ongoing learning among professionals is clear. Much of this learning must be done outside of a formal classroom, so self-directed learning is a key skill for computing employees, as confirmed by an earlier study [Zander et al. 2012] of industry professionals. It follows, therefore, that preparing students to learn on their own should be a basic consideration in how we teach our students. Some of our undergraduates already do self-directed learning of computing topics—if we can understand what motivates them, it will help us to teach other students this key skill.

Based on semistructured interviews with 17 students in three countries, we found four main themes: projects, social influences, the joy of learning, and fear. Within those themes there were more specific subthemes.

First, students were motivated by projects in a variety of different ways. Sometimes they learned to complete projects they did for fun, sometimes the projects were assigned in connection with a class, and sometimes they were work assignments. They talked about problem solving and the drive to make things work. In those cases, the projects came first and motivated the learning. Notably, sometimes it was the other way around. Students also reported creating projects for themselves to learn something they needed to learn.

Second, students were motivated by social influences, including doing what others think is cool, avoiding letting others down, and being encouraged when others are impressed with what you have done.

Third, students were motivated by the sheer joy of learning. Under this theme, we also considered students who were motivated by a desire to improve their skills.

Finally, students were motivated by fear: the fear of being foolish or of looking foolish to others.

Some implications for teaching follow from these results:

—We can make all students aware of the importance of self-directed learning in their future careers.
—We can give students scaffolded opportunities to practice SDL as part of their undergraduate studies.
—SDL provides a mechanism for students to learn additional topics, beyond what is explicitly covered in the curriculum.
—At least some students can be motivated to do SDL by project work and by social interactions.

This work also raises several questions that might be fruitfully studied in the future. First and foremost, how broadly do these results generalize? One could examine the motivations for self-directed learning in institutions that are geographically and culturally different or among both freshmen and more advanced students. Second, by choosing students who had experience with SDL, we did not hear from those students who did not. Looking at that population could provide broader insights into motivation; as an example, we might determine how they are affected by things like projects and social interaction that motivated the students in our pool. Finally, if we are going to give our students scaffolded opportunities to teach themselves, what is the best way to do this? When are our students ready for self-directed learning, what types of SDL tasks can they handle at what point in their learning, and what sorts of activities can best prepare them?

Some other questions about SDL that would be interesting to investigate, although they do not arise directly out of this project, include the following. First, are there differences between motivation and volition (in Corno's [1993] sense)—that is, are choosing a task and persisting in a task done for different reasons? Second, how much of student learning can or should be done using self-directed learning? Are there particular topics that lend themselves to SDL and others that are best learned using more traditional approaches?

APPENDIX

Script for Semistructured Interview on Informal Learning

(1) Tell me about something (computing) you learned informally. What did you learn from this experience for the next time? How do you know how to go about learning it?
(2) Why did you choose to learn this?
(3) How did you learn it? In what context did this happen? (Did you learn it in some community? Online? How much did you use the Internet?) How do you know your source is reliable? (Note: Keep probing to get at the details. For example, talked to some guys—how did you find them? Googled it—what you search for? what was your strategy? How do you know how to go about learning it?)
(4) Were there other people involved? (Follow up, clarifying: Were you working with a group or alone?)
(5) Was there a point where you became stuck or discouraged? Why did you persist?
(6) How did you use it once you learned it?
(7) Did you learn as much as you wanted to? How could you tell that you had learned it?
(8) If you were to give advice to a friend on how to learn [X], what would you say?
(9) Reflect on this experience: What did you learn from this experience for the next time?
(10) How did this compare to your "more traditional" experiences learning things in school? (Possible data to get at: Did they learn how to informally learn from formal learning?)

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