Deciding to Major in Computer Science: A Grounded Theory of Students' Self-Assessment of Ability

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ABSTRACT
There is great interest in understanding and influencing students' attraction to computing-related majors. This qualitative study is based on interviews with 31 students enrolled in introductory programming courses at two public universities in the United States. This paper presents a model of five factors that influence student decisions to major in CS and elaborates on our grounded theory analysis of one of these factors: how students assess their CS-related ability. We describe how students measure their ability in terms of speed, grades, and previous experience and how students make interpretations and decisions based upon these measurements. We found that students' interpretations were influenced by experiences in their environments and beliefs about ability as being fixed or malleable.

Categories and Subject Descriptors
K.3.2 [**Computers and Education**]: Computer and Information Science Education – *computer science education, self-assessment*

General Terms
Human Factors

Keywords
Ability, major choice, grounded theory

1. INTRODUCTION
Although there are signs of a possible turnaround in the sharp drop in undergraduate computer science (CS) enrollment in the U.S., levels are still very low and unlikely to be sufficient to meet projected demand [15, 29]. Accordingly, there is great interest in understanding student experiences and perceptions of CS, as well as how they shape student decisions to major. For example, Margolis and Fisher documented undergraduates' experiences of CS and reasons for leaving the major [19]. Barker and colleagues identified aspects of CS classrooms that create a hostile and defensive environment [3, 4]. Other work that examines students' interest in CS and how they select CS as a major has been primarily quantitative [5, 6, 7, 12]. This quantitative work bears the risk of missing subtle, unanticipated ways in which students' experiences and perceptions influence their decisions about majoring. To remain sensitive to these subtleties in students' decision making, we selected a grounded theory methodology [8, 27], which is an inductive and iterative research approach that explores the variety of responses that emerge from the data for the purpose of developing an explanatory theory for a phenomenon.

We conducted a qualitative analysis of interviews with students at two large, public universities in the U.S. From the data, we identified five factors that students assessed in deciding whether to major in CS. These factors were ability, enjoyment, fit, utility, and opportunity cost. For this paper, we have selected a single factor, *ability*, and will present our theory, developed using grounded theory. Our theory details the types of measurements of ability made by students, their interpretations of those measurements, and their decisions based upon those interpretations. An integral part of the theory describes how students' experiences of their academic and institutional context, as well as their beliefs about CS ability as being fixed or malleable, influence interest in the CS major.

Related work has documented that there is a common assumption of the existence of an innate aptitude that determines students' success learning to program [18, 23], which education research has found can lead students to pursue less effective learning strategies [10]. The belief that some students cannot succeed in CS also has the potential to disenfranchise populations and exacerbate the lack of diversity in computing [10, 25]. As educators, we hope to provide all motivated students with environments in which they can become competent at programming, and we seek to understand students' processes of self-assessment, as well as the myriad influences that shape them.

This paper contributes a theory for students' self-assessment of ability in deciding whether to major in CS. It describes how both internal and external influences, particularly student beliefs about CS ability and a competitive context, affect how students measure ability and how they interpret and act on those measurements. Grounded in interview data, the details of how these influences interact with self-assessment to impact interest in CS offer educators new insights on ways they can dramatically shape students' experiences, learning, and motivation.

2. PREVIOUS RESEARCH
Previous research on high school and college students' interest/disinterest in CS provides valuable but fragmented insights on the topic. Based on surveying high school students, Carter found that expectations of having to sit at a computer all day, prior interest in another major, and interest in a more "people-oriented" field were common reasons for disinterest in CS [7]. From interviews with 18 CS minors who dropped CS1,

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Kinnunen and Malmi identified lack of time and motivation, low comfort level in class, and prior commitment to a non-CS field as commonly cited reasons [14]. In a quantitative survey of 113 students who had taken introductory CS, Barker and colleagues found that student-student interaction was the most powerful predictor of students' intention to continue studying CS [3, 4]. Higher education research has identified similar influences and predictors for major choice, including social supports and barriers [17], personality and values [1, 22], and demographics such as gender, race, and socioeconomic status [13]. Given these disparate findings, it is productive to develop theories, such as the one presented in this paper, which can synthesize findings and provide rich qualitative details to aid practitioners in interpreting the theory within their local context.

3. METHODOLOGY

3.1 Interview Sites

Interview data was collected in the U.S. at two large, public, research-focused universities. University A has a two-course introductory programming sequence (UA-CS1 and UA-CS2) taught in Java using an "objects late" approach. UA-CS1 is taught with a weekly format of three 50-minute lectures with over 200 students and one 50-minute quiz section, typically led by an undergraduate teaching assistant, with 15–25 students. The format of UA-CS2 is identical except it has two 50-minute quiz sections per week. There are two majors at University A that enable students to pursue CS. For the purposes of this paper, the differences are unimportant, and we use "CS" to refer to both. Admission to the CS major is competitive at University A. Less than 25% of majors are accepted directly out of high school. Most prospective majors apply after two years of prerequisite course-work, and approximately 40% are accepted.

University B has a course sequence that begins with an optional course (UB-CS1). Advanced Placement CS or UB-CS1 serve as preparation for the first official course for majors (UB-CS1.5). UB-CS1 is taught in Scheme with six hours of closed lab and a single hour of lecture a week. Each lab section has approximately 30 students and a single graduate or undergraduate teaching assistant. Students interested in pursuing CS at University B can do so in the College of Engineering (EngCS) or in the College of Letters and Sciences (CS). For EngCS, students indicate their intention to major on their university application and are selected through a competitive admissions process, with less than 15% admitted and the rest denied admission to the university. For CS, students apply for the major after enrolling at the university and completing several prerequisites. At times this process has been competitive, but in recent years this has not been the case.

3.2 Data Collection

At University A, nine participants were recruited from UA-CS1 and eleven participants were recruited from UA-CS2. At University B, eleven participants were recruited from UB-CS1. All participants responded to a recruitment e-mail and were compensated $15. Of these 31 students, about one third intended to major in CS, and an additional third were unsure or intended to minor, with the rest not intending to major or minor. Just over half of the students in the sample were women. At UA, women were oversampled and at UB no screening was done. While the two universities are similar, we relied on the differences in these populations to provide variation in experiences and attitudes.

The interviews used a semi-structured interview protocol, which affords the interviewer the flexibility to pursue unanticipated, relevant topics but does not guarantee that all participants are asked the same questions [8]. The interviews proceeded in a conversation-like pattern, with the interviewer asking follow-up questions. Topics included students' experiences in the current CS course, academic interests, and interest in and preconceptions of CS. Interviews lasted 30–60 minutes and were audio recorded and transcribed. Quotes in this paper are associated with anonymous identifiers including university and course level.

3.3 Data Analysis: Grounded Theory

We developed a *grounded theory* [8, 27] of students' assessments of their CS ability in shaping their decisions to major in CS. We selected grounded theory to identify the range of factors that shape student decisions to major and the context in which they operate and interact. This inductive and iterative research approach is commonly used to collect and analyze qualitative data to form and substantiate explanatory theories. The grounded theory approach differs from research approaches that test *a priori* hypotheses and is a particularly appropriate method to highlight and value participants' individual experiences.

Our analysis began with the coding of noteworthy patterns in the data, referred to as open coding within grounded theory. Based upon this initial open coding, we identified dozens of codes related to an emergent high-level theme of what students think it takes to succeed in CS. Codes were clustered into categories that represented the higher-level patterns and connections between the codes, referred to as axial coding within grounded theory. Throughout this coding process, we negotiated definitions for approximately 75 codes and 25 categories, and continually developed or refined codes and categories to represent the variation and themes within the categories.

In an attempt to narrow our analysis, we focused on students' responses to interview questions about what makes majoring in CS interesting and appealing or uninteresting and unappealing. Returning to open coding on this subset of the data, we developed 39 new codes for students' responses to these questions. During axial coding, these codes were then clustered into five categories that students linked to their decisions to major in CS or not: ability, enjoyment, fit, utility, and opportunity cost.

We found that the factors that students listed as interesting and appealing or uninteresting and unappealing appeared throughout the interview. For example, one student considering a CS major mentioned his perception that CS becomes increasingly competitive as something that makes CS less appealing. He described it as *"a little bit more competitive...that there is less that spirit of collaboration" (UA_CS1_007)*. His response tells us that some students consider the competitive environment when deciding upon a major but does not give a rich sense of students' experiences of competition. For each of the 39 codes, we returned to the entire data corpus and initial 75 codes to elaborate on the variation amongst students' experiences and beliefs. In the sections below, we do not distinguish between students that have decided to major or not. Instead, we focus on the variation in students' experiences and beliefs related to one of the five factors that students cited as affecting CS interest or appeal.

In developing a grounded theory of the factor of self-assessment of ability, we gathered codes that were relevant to understanding the process of measurement and interpretation of CS ability. From our data, we noticed that students' interpretations of assessments were shaped by their perceptions of context, their beliefs about ability, and their specific methods of measurement. These connections in the data formed the wire frame of the initial drafts of our grounded theory. Throughout our analysis, we returned to the transcripts, codes, and categories in an attempt to refine our theory. We schematized the process of students' assessment of ability in parallel to comparing our model to a diagram template used in some grounded theory work [26]. Our resulting model, discussed in detail in the Results section, is a modified version of a traditional diagram, customized to match the specifics of our process of interest.

4. THEORETICAL FRAMEWORK

During analysis, research by Dweck and colleagues [10, 20] shed light on the emerging codes and categories and was subsequently incorporated into our theory. Dweck and colleagues have found that the belief that intelligence or ability is fixed (*e.g.*, innate) is associated with avoiding challenges, giving up in the face of difficulty, and other "maladaptive" learning behaviors. In contrast to students with this "fixed mindset," students with a "growth mindset" believe that intelligence or ability is malleable (*e.g.*, extensible through effort), which is associated with challenge seeking, persistence, and, ultimately, attainment of learning goals. Particularly relevant to our grounded theory of self-assessment of CS ability are the ways in which mindset can affect interpretations of achievement and failure. A student with a fixed mindset concerning CS ability might take a low exam grade as a sign that they are ill-suited for CS study, while one with a growth mindset might, from the exact same grade, conclude that they need to study harder and prepare differently for future exams. This example illustrates how the belief that CS ability is innate can impact learning behaviors and motivation, potentially stifling academic growth [10, 24]. A survey of faculty and students suggests that the belief that CS ability is fixed is not uncommon in the field [18].

5. RESULTS

5.1 Five Factors that Shape Decision to Major

Our interviews suggest that students consider some combination of five interrelated factors in deciding whether to major in CS:

- Their **ability** as related to CS: experiences and expectations of success as CS majors
- Their **enjoyment** of CS: how much they would enjoy majoring in CS
- The **fit** between their identity and CS: the extent to which their own values and identity align with values and cultural expectations they associate with CS
- The **utility** of CS: the extent to which CS would provide potential value to society or to them as individuals
- The **opportunity cost** associated with majoring in CS: practical constraints, as well as ways in which majoring in CS might restrict other plans

5.2 A Grounded Theory of Students' Assessment of Ability

This paper describes a grounded theory for the first of the five factors, with the central focus on students' self-assessment of their ability as related to CS. Below we present an overview of the theory as diagrammed in Figure 1 and in the paper elaborate on the variation and themes within each node and the influences between nodes. In parentheses below, we indicate the traditional labels used in similar grounded theory diagrams [26].

To characterize students' process of self-assessment, we separated it into two sequential stages: *measurement* and *interpretation*. In our theory, *measurement* of ability (Central Phenomenon) refers to uninterpreted measurements of ability, such as course grades and speed completing assignments. The process of *interpreting* these measurements of ability (Strategies) is distinct from the uninterpreted measurement. Sometimes measurements were explicit, and sometimes measurements were visible only through students' interpretations. For example, the following quote includes multiple interpretations and implies a measurement: *"In sixth grade, I tried to learn some HTML, but I don't think that counts" (UB_CS1_04)*. An element of interpretation from the quote is the attitude that her experience with HTML does not count as previous experience with CS, and she explicitly devalued this measurement. Her qualifier that she *"tried to learn"* suggests an additional interpretation, potentially that she considered herself not fully successful in learning HTML. From this quote we can infer that this student considered her sixth-grade experience with HTML, which we classify as a measurement. Frequently, only from these interpretations can we infer specific measurements that inform the interpretation.

We identified the need to select a major and the belief that ability is relevant to major selection (Causal Conditions) as conditions that caused students to measure their ability (Central Phenomenon). Interpretations of measurements (Strategies) were shaped by students' experience of their external context (Context) and students' beliefs regarding whether CS ability is innate (Intervening Conditions). These interpretations informed students' major decisions (Consequences).

For the purposes of this study, we customized a common grounded theory diagram by distinguishing between *intervening conditions* and *context* as follows:

- *Intervening conditions* are internal to the student and refer to beliefs held by the student. In the analysis of the central phenomenon of measurement of ability, the key beliefs pertain to the fixed or malleable nature of CS-related ability.
- *Context* includes aspects of the external environment as experienced by the student. Key elements of the external environment are the student's institutional and departmental context, peers and instructional staff, and educational experiences. In particular, perceptions of a culture of competition among students were a significant aspect of the external context at one of the studied institutions.

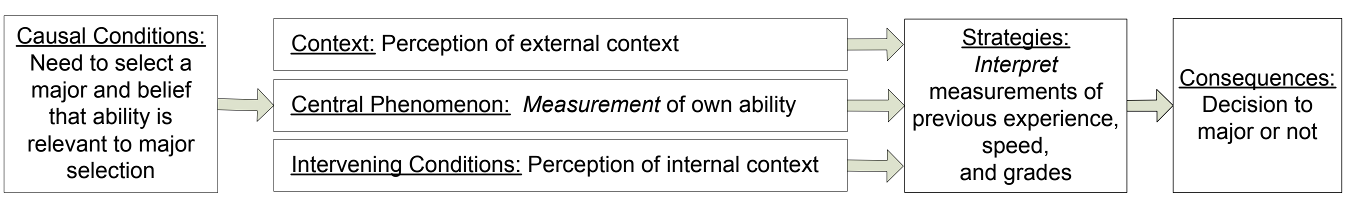

Figure 1. Diagram of grounded theory of students' assessment of CS ability

We begin by describing students' perceptions of intervening conditions, external context, and three ways students described measuring their ability: previous experience, speed, and grades. Later we discuss how intervening conditions, external context, and self-measurements were interpreted by students and influenced their decisions to pursue a CS major.

5.3 Intervening Conditions

In this study, we define intervening conditions to be the key beliefs of students relevant to assessment of ability. We focus on the spectrum of students' beliefs about the fixed or malleable nature of CS ability, which informed our selection of the theoretical framework based upon research by Dweck and colleagues [10, 20]. From our data and the work of Dweck and colleagues, we have evidence that these beliefs influence the ways in which students interpret measurements of their ability. There were instances where participants identified CS ability as shaped by effort, while other times, students discussed assumptions about CS ability or CS ways of thinking as something *"you are just born with" (UA_CS2_104)*. To characterize the intervening conditions, we elaborate on the variation within students' beliefs regarding CS ability, the potential sources of this information, and the potential consequences for student learning and motivation.

There is a sense among many students that it is necessary to have a natural inclination toward CS, from which students appear to derive both negative and positive motivation. One student explicitly linked a decision to become a CS major to the presence or absence of a natural inclination: *"You know it's not your thing because you know, you're not learning it. It like doesn't come naturally to you... If programming comes naturally to you, then being a CS major would be like a good choice I guess" (UB_CS1_07)*. In listing reasons to not major, another student included in the list that they *"don't have any natural ability" (UA_CS2_111)*. In contrast, one student explained their enjoyment of UB-CS1: *"I guess 'cause programming comes to me pretty naturally" (UB_CS1_10)*.

On the other hand, some students identified effort as crucial to their success: *"I'm sure if I try hard enough I can learn" (UB_CS1_09)*. Many students identified *"hard working" (UB_CS1_01)* as an important trait for a successful computer scientist. Some students emphasized the role of effort in achieving success in CS: *"Success in [UA-CS2] is basically all up to you, as far as how much you want to put into it and learn" (UA_CS2_105)*. Another student attributed a bad grade to his lack of effort, not an aspect of innate ability: *"If I had committed myself, I would have gotten a better grade" (UA_CS2_110)*.

We hypothesize that sometimes information about whether CS ability is innate or malleable comes from faculty. One student reported that their instructor directly tied students' success or failure to a *"mental outlook" (UA_CS2_101)* that you are born with, which can be either compatible or incompatible with CS: *"Even my [UA-CS2 professor] told us that some people are just born that way, with that mental outlook that is compatible with CS… They feel it's so easy for them... Yeah, and he told the rest of the people that some of you will try but some of you won't get it, and it's just that your mental outlook isn't made that way. It's something you're born with. You can't help it" (UA_CS2_101)*. This student said she now believed this but had not heard or believed this idea before hearing it from her professor.

One reason that expectations of ability being innate are problematic is that they provide the opportunity to disenfranchise an entire community. One student expressed that male students' inclination to CS is innate: *"I think like the girls and guys have different kind of system of thinking, just like, I just think guys are more used to thinking the way that the programming language is thinking... I think that's an inherited thing, like you are born with those characteristics" (UA_CS2_104)*. She generalized about men's and women's performance at UA, saying, *"I have to admit that guys do perform better than girls in the [CS] courses" (UA_CS2_104)*, and drew further evidence from the fact that there were more male than female teaching assistants.

The range of attitudes toward CS ability can be expected to exaggerate or temper interpretations of assessments of ability, negative or positive. Whereas one student above (UA_CS2_110) tied his bad grades to a lack of effort, it is likely that another student may associate a bad grade or even difficulty on an assignment with a lack of innate ability.

5.4 Context

Context is the external environment as experienced by the student. Key elements of the external environment are conversations with and observations of peers. Perceptions of a culture of competition among students were also a significant aspect of students' experience of the external environment at UA.

5.4.1 Conversations with and Observations of Peers

In our interview data, students often described information they learned both from talking to or observing their peers that influenced their interpretation of their own ability.

Students formed opinions about their peers from first- or second-hand accounts of other students' experiences. One participant reported that *"they told me that even though they have done something similar to [UA-CS2], they are still taking this class" (UA_CS2_101)*. Students also heard stories of other students, often those with previous experience, who purportedly received good grades with ease. One UA-CS2 student reported that her friend skipped UA-CS1 and *"found [UA-CS2] really easy and got a 4.0" (UA_CS2_101)*.

Some students mentioned that they observed the behavior of others during class in gathering information about the ability and experience of their peers. At UA, one student discussed her observations of students pretending not to listen: *"When I look around the room, I notice how students will pretend they're not listening to the lecture at all... They will play chess on laptops, just to show that like, 'Oh yeah, this is a piece of cake for me.' ...You see a lot of people playing games" (UA_CS2_103)*. Another student noted that some students finish labs quickly: *"There are people that leave so early! It's like, 'Whoa you're done already?'" (UB_CS1_03)*.

5.4.2 Competition at UA

In UA interviews, competition among students was a common theme related to assessment of CS-related ability. UA students perceived competition as part of both the process of gaining admission to the CS major and their experience of the introductory CS courses. Such discussion was largely absent in the UB interview sample; however, at both institutions, some students discussed a perception of CS courses lacking collaboration and collegiality.

Many UA students described the CS admissions process as being competitive in general, saying that the admissions rate was low, and that it was *"really competitive"* or, worse, *"nearly impossible."* Knowing about students who were denied admission reinforced these perceptions. Many UA students believed that exceptionally high grades, particularly those in the introductory CS courses, were critical to admission and were told this directly by non-CS-specific university advisors. Students drew similar conclusions concerning the importance of grades from what they observed in and heard from their peers. There were also accounts of students strategically retaking CS1 or CS2 to get higher grades and boost their chances of admission.

Some UA students described their introductory CS courses as having a competitive atmosphere. This was especially true of UA-CS2, which multiple students described as having a reputation of being a *"weed-out"* course that the department used to select out higher-achieving, *"super-smart"* students. In such an environment, students reported feeling *"discouraged," "like an outsider,"* and *"lonesome."* A few students saw competition among students as a direct consequence of course grading, which they incorrectly believed to be curved. Concerns about competition in the introductory courses were heightened by recognition that students with a wide range of prior programming experience enroll in the same introductory course sequence.

UA students and a few UB students described their experiences in introductory CS as lacking collaboration and collegiality. While not necessarily symptomatic of competition, one student believed that the *"antisocial"* nature of CS gave rise to a feeling of "*you against the rest of the class" (UA_CS2_103)*. Other students' observations concerning the lack of collaboration used words like "*isolation," "snobby," "separated,"* and *"individual."* At UA, students were *"scared"* of talking about assignments at a conceptual level, for fear of being accused of academic misconduct.

It seems likely that if students perceive themselves as competing with other students, they will be more likely to assess their ability, and it will shape their interpretations and decisions based upon these assessments.

5.5 Central Phenomenon: Measurements of Ability

From students' statements, we can infer that they gathered information that informed their interpretations of their CS ability. We refer to students' methods of gathering information as measurements, and we identified three primary ways that students measured their ability: the amount and type of their previous experience, the speed with which they accomplished various tasks, and the grades they received.

5.5.1 Previous Experience

Students considered specific personal experiences, both formal and informal, in assessing their previous experience. Some students made factual statements about their experience during the interview, and the following interview prompt, used near the end of the interview, asked students about their experience: "In total, how many years of computer programming experience would you say you have, including both in-course and extracurricular experience?" For example, one student responded, *"I took a Visual Basic class in high school" (UA_CS1_007)*.

5.5.2 Speed

Students considered their speed completing tasks such as exams or programming assignments as a way of assessing their CS ability. It was rare for students to provide concrete information about the time taken on CS assignments. In one exception, a student quantified time spent on CS assignments: *"a couple of them did take a couple days" (UA_CS2_103)*. Instead, students evaluated the time spent with interpretive descriptions such as *"forever," "a lot,"* and *"really long."* This kind of interpretation was common, and we have little information about the actual measurements students made of their own experience of time to inform these interpretations.

5.5.3 Grades

Students used their course grades, as well as grades on exams and homework, to assess their CS ability. Students at UB had relatively fewer opportunities for measurement, given the timing of the interviews. Students interviewed at UA had nearly completed their first or second university-level CS course, whereas most of the UB students were interviewed before their first exam in their first university-level CS course. This might partly account for the greater amount of discussion about grades in the UA interviews.

5.6 Strategies: Interpretations of Measurements of Ability

To elaborate on our theory, schematized in Figure 1, we detail students' interpretations of their measurements of previous experience, speed, and grades, as influenced by intervening conditions and external context.

5.6.1 Previous Experience

We identified four patterns of interpretation of previous experience measurements. Students evaluated their level of experience, the relevance of their experiences, and their experience relative to their peers, and they made inferences about the climate of the class. These interpretations were shaped by students' measurements, their internal beliefs, and their context, such as the experiences of their peers.

Some students provided interpretations of their measurements of previous experience, irrespective of their peers. One student responded regarding his previous experience and described it as *"probably one year of dedicated work" (UA_CS2_106)*, and he later interpreted this experience as *"still very, very novice" (UA_CS2_106)*. Another student reported on his experience as being *"three-quarters of a year"* and characterized it as *"not a whole lot" (UA_CS1_003)*.

Students had both positive and negative evaluations of whether their prior experience was relevant. One student deemed her experience to be relevant: *"But it was familiar and kind of easy because I understood the concepts because I had programmed before" (UA_CS1_009)*. Another student reported, *"Freshman year of high school, first semester, I took a computer programming class which was Visual Basic... I guess that kind of helped me with some concepts, I think" (UA_CS1_002)*. In contrast, another student interpreted a required Visual Basic course in high school as not relevant and explained, *"I don't really count that, because I don't think that's computer science... It was all memorizing... It didn't teach you how to write your own code" (UA_CS2_104)*.

Some students used measurements of their previous experience and information from their context to come to conclusions about their level of experience relative to their peers. Many students appeared to believe that their peers had more programming experience. One UA student likened his introductory course experience to being in a foreign language class with classmates who were already native speakers. He described how they impacted the course: *"Everyone else already knows what's going on, so you'd think that would help you more, but the teachers* *start to adjust to the natives, so the people that are completely new to the idea are getting left behind in the dust, unless they work their asses off" (UA_CS2_109).*

In drawing implications for classroom climate, one student expressed being intimidated to ask questions in her classroom that she identified as having many people with prior experience: *"It's intimidating to ask questions, 'cause you feel like people are going to scoff at you, like, 'How do you not know that?' And you're like, 'Because I didn't take AP computer science. Because I haven't been programming since I was four'" (UB_CS1_02).*

5.6.2 Speed

Students interpreted their measurements of speed to inform their opinion of their personal speed as well as to inform their opinion of CS. Students' interpretations can be divided into two groups. Some students identified external factors that shaped their experience of speed within the course, while other students focused on their personal experiences without attribution, making it unclear whether they interpreted these experiences as within or beyond their control.

Students sometimes attributed their speed to external factors such as exam pressure, the course's pace, peers' experience level, and the time-consuming nature of programming. Taking a long time to complete an exam was often attributed to the nature of the exam: *"I feel like we were tested more on how fast we could do it, as opposed to how well we knew the material" (UA_CS1_008).* However, one student interpreted a similar experience from an apparent mindset that ability is malleable: *"On my midterm, we had time limits and pressure and stuff, so... I mean I guess I did not study enough" (UA_CS1_005).* Some students perceived a mismatch between the amount of material being taught and the number of weeks in the course: *"Too much information was given to us, and we were given too little time to master it" (UA_CS2_101).* Finally, some students attributed their assessment of slowness in learning material to the fact that other students had more experience: *"It takes a little bit longer to grasp concepts… I just need more time to read and understand and practice… Maybe the majority of them have more experience" (UA_CS2_103).*

Some students stated that being *"a fast learner" (UA_CS1_003)* was a trait of a successful computer scientist, and this kind of speed could be interpreted as either within or beyond students' control. One student (UA_CS2_105) reported that, due to the time pressure on exams, he specifically practiced solving problems quickly. Many examples were not explicit in attributing speed to innate ability. However, consistent with fixed mindset, these also did not include attribution to an external cause or draw implications for their effort. For example, one student reported that the amount of time needed to complete the assignments was *"kind of discouraging" (UA_CS2_103)*. Students described interpretations that they were slower than their peers and general interpretations that their time spent programming was *"longer," "forever,"* or *"lots"*: *"I think I take a longer time [coding] than most people" (UB_CS1_06),* and *"I know it takes me forever to think through a problem and finally come up with the code that'll work" (UA_CS2_108).*

Students also came to conclusions about speed and the nature of CS work. For one student, this was based in part on her experiences in UA-CS1: *"I think it like takes a few hours or a few days to like think and actually program stuff" (UA_CS1_005).* Without referencing ability measurements, other students made general statements about CS work being *"really time-consuming" (UA_CS2_101)* or that *"it takes a long time" (UB_CS1_02).*

5.6.3 Grades

Students interpreted their grades as both reflective of their ability and unfair in the context of a class where many students have prior experience.

One student interpreted her grades as information about her ability to handle the workload in the course and thus the field: *"I would realize, if I had gotten a higher grade, I would think that, okay, the amount of hard work I put in was sufficient enough. Right now I feel like, even though I worked hard, I'm not getting a good enough grade" (UA_CS2_101).* Another student interpreted an exam grade as a positive reflection of his ability: *"When I first got my score, I was like, 'Yes!', you know? 'I rock at this!'" (UA_CS2_110).* We saw evidence that some students felt that grades were unfair or otherwise provided inaccurate information about their learning: *"I feel like I understand, like I learn a whole lot, but my grade's not going to show it" (UA_CS2_108).*

Students at both universities referenced the existence of competition in the form of a grading curve, where students with previous experience had an inherent advantage: *"They mess up the curve. You're always thinking about that" (UB_CS1_07)* and *"It's hard to make the curve, because a lot of people in there are already like, 'Man, I'm already good at programming. I don't have to study. Watch me get a 4.0'" (UA_CS2_109).* One student felt that first-time programmers did not have a reasonable shot at getting a good grade in UA-CS1 and UA-CS2 (UA_CS2_101). At UA, university-level advisors were even reported to suggest to a student that they take a CS course during a particular term based on how many people with previous experience were expected to enroll (UA_CS2_108). Having a "good enough" grade was so important for admissions at UA that taking the course over again was a strategy used for getting a better grade and increasing chances to get into the major (UA_CS2_104).

5.7 Consequences: Decision to Major or Not

5.7.1 Previous Experience

Students drew both positive and negative conclusions about majoring in CS from their interpretations of their previous experience measurements. One student discussed his two reactions: *"Part of me was kind of like, 'Major in it! Fight the power!' and stuff like that, but the other part of me was like, 'Do I really want to be in a major like that, where you know a lot of these people were experts in their field before they even started college?'" (UA_CS2_109).* One student contrasted her frustration with others having more experience with her enjoyment of the course: *"And people have programmed like since they were eight, so it is impossible to start learning a new language in college and catch up with them. So I was not sure if I should take [UA-CS1] or not, but, it is fun" (UA_CS1_005).* A student with high school programming background linked his ability as motivation to continue pursuing CS: *"Also that I'm good at it. That is encouraging. I mean, if it is something that I enjoy and I'm good at it, that is a lot of encouragement to continue forward" (UA_CS1_007).*

5.7.2 Speed

Students explicitly connected their speed and the amount of time that CS work requires to decisions to pursue CS. One student, based upon their interpretation that some people overcame difficulties faster, said that this *"makes you feel like, 'I might not be best fit in this field'" (UA_CS2_110)*. In contrast, one student felt well-suited for CS on account of his speed: *"I feel I can learn things quickly" (UA_CS1_003).* Another student connected programming speed with prior experience and expectations of admission to the major: "*This is my first time, and I take really long to program something. So like, I don't think I have enough experience I think. So, I'm not sure if I can get into the major" (UA_CS1_005).* Other students concluded that majoring in CS would take too much time: *"Like if I chose CS, I know that I'll have to put in like so much time in the lab... I knew it'd be time consuming" (UB_CS1_07).*

5.7.3 Grades

Students drew both positive and negative conclusions from their interpretation of their grade measurements. Sometimes bad grades were enough to discourage students from pursuing the major, as one student noted: *"I enjoyed the homeworks… The hard work was worth it, but once you see the grades, and I guess the way I analyzed was, once I go into the 300-level classes, it's going to get tougher, and if I'm not good enough in the 100-level courses, then I should back out right now. It's not going to get any easier" (UA_CS2_101).* Another student mapped their assessment of grades, interrelated with the issue of previous experience, to the decision to major: *"It kind of sucks, because like, when you try to apply for a competitive major, you're basically competing against someone that's had five or six years on you" (UA_CS2_109).* Good grades could encourage students to pursue the major: *"My own performance in these two courses, so, like spur some of my intention to get into the major" (UA_CS2_104).*

6. DISCUSSION

The fact that students consider their CS-related ability when deciding whether to major in CS is consistent with a variety of long-standing theories concerning motivation and achievement-related choices [2, 11, 16]. The grounded theory presented above details the specifics of how students went about measuring their ability, how these measurements were influenced by internal and external context, and how they were linked to interest in the CS major. Our analysis indicates that students employed information in three categories as the basis for their measurement and interpretation of CS-related ability: previous experience, speed, and grades. Students often deemed previous experience with programming as relevant, but not other computing experiences (*e.g.*, Microsoft Office or HTML). Measurements of ability related to speed mostly considered the time required to complete exams, programming assignments, and labs. Finally, grade-based measurements were based primarily on exam and homework scores, as well as grades in previous CS courses.

Partly based on the information described above, students interpreted measurements of their CS-related ability. Students at both institutions also considered information about external context, such as conversations with and observations of peers. Internal context, specifically beliefs about the fixed or malleable nature of CS ability, also influenced assessments of ability. In turn, these interpretations led students to various decisions regarding whether to major in CS and a variety of conclusions about themselves, their peers, and the field and culture of CS. Particularly at UA, competition and perceptions of peers engendered comparisons with peers. These comparisons of ability led students to different conclusions about their prospects of success as CS majors.

7. VALIDITY AND LIMITATIONS

In interpretive qualitative research, subjectivity is inherent in the process, but we attempted to address related validity concerns in our study's analysis and presentation. All three researchers have experience teaching introductory CS courses and background in education research in CS and engineering. This meant that we were familiar with the language of CS, as well as the pedagogical context, which guided follow-up questions during interviews and aided data interpretation. In addition, interpretations and conclusions presented here were the result of negotiations by at least two researchers who examined transcript data. Finally, in keeping with qualitative traditions, we offer the reader context and numerous quotes for our claims, allowing them to make judgments of validity.

As is common with grounded theory work, our goal was not universal theory, so we make limited claims about the generalizability of our findings and the prevalence of observed phenomena. We do, however, expect that many of the complex relationships our theory describes apply to other settings. We described the interview sites to help readers determine the transferability of findings to other contexts.

A potential limitation was the fact that participants were self-selected volunteers. However, the sample included roughly equal numbers of students intending to major, considering majoring or minoring, and not intending to major in CS, suggesting limited relevance of self-selection bias. A clearer limitation stems from our sole focus on the perceptions of students. Important as they are, we expect there are other influences on interest in majoring in CS that students are not conscious of or do not self-report for some other reason.

8. CONCLUSION

This paper presents a grounded theory for one of five factors that we found students considered when deciding whether to major in CS: ability, enjoyment, fit, utility, and opportunity cost. Based on interview analyses, our theory details the different kinds of information that serve as bases for measurement of CS-related ability. It also describes how students interpret and respond to these measurements, subject to a variety of contextual influences. Some of these influences represent external context, such as peers' behavior or speech and admission policies that induce competition, as at UA. We also observed the influence of internal context, particularly in the form of beliefs about the nature of CS-related ability—*i.e.*, whether it is innate or extensible through effort.

Assuming that one role of introductory CS courses is to help students make informed decisions about majoring in CS, CS educators can reflect on ways in which they can influence the self-assessment process as modeled above. Are speed, prior programming experience, and grades in introductory courses appropriate metrics, given mixed empirical evidence of the latter two's value in predicting longer-term success in undergraduate CS [19, 28]? How can educators affect these measurements and interpretations through decisions about curriculum, courses, and classroom environment? Our theory identifies multiple points of influence in the process linking self-assessment of ability to interest in majoring.

Despite efforts at UA to make CS more accessible, competition significantly influenced how students interpreted their measurements of ability. Comparisons with peers with respect to prior programming experience and speed caused some students to question whether they should pursue their interest in CS.

Competition also led students to characterize introductory courses as weed-out courses and associate CS with a culture of isolation. Faculty and advisors have some control over competition and its effects on students by addressing misconceptions about grading policies and admissions criteria. Given heightened concern among novice programmers at UA about competing with more experienced students, educators might consider entry paths tailored for students with no prior programming experience. Regardless of admissions process, integration of cooperative and collaborative learning might challenge cultural stereotypes and set more accurate expectations of CS professions.

Our theory provides CS-specific examples of how a student's mindset can affect self-assessment of ability and, ultimately, motivation to major in CS. Given this and the extensive research of Dweck and colleagues on the negative learning behaviors associated with fixed mindset [10], CS educators should consider the risks of endorsing unsubstantiated assumptions that CS ability is fixed. Further research is needed to examine potential connections between mindset and the persistent gender gap in CS, as suggested by Murphy & Thomas [21], as well as CS-specific interventions to influence mindset [9, 24].

Our future work includes developing theories for the remaining four factors related to interest in majoring in CS, as well as interactions among them. This body of work might inform a quantitative study to further validate causal relationships and document the prevalence of various beliefs and experiences. We hope these investigations will directly inform the design and validation of interventions to help potential CS students make informed major choices.

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