FFF: Floundering, Frustration, and Failure in Computer Science

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Project Summary

I. Objectives

We propose an integrative interventions project that consists of a four year study in determining how the perceptions of frustration and failure lead students to leave the computer science (CS) major, culminating in the actual implementation of classroom interventions based on our findings. Through this, we will advance the understanding of foundations of cognitive processes in realistic, complex environments, namely the cognitive processes utilized by learners of CS, individuality, and variation.

I-A. Methods to be Employed

A group of 30 students is selected from the incoming Introduction to CS classes (CSCI 1300) at the University of Colorado at Boulder. Signup is voluntary, with weight added to the acquisition of underrepresented students in CS. Selected students conduct entry and exit interviews to determine perceived self-efficacy changes toward the CS discipline, with exit interviews conducted either just prior to completion of a degree in CS, or following a decision to withdraw from the CS major. Additionally, selected students undergo video and audio recordings during assignments, study time, and exams, in order to identify key frustration events that influence perceived self-efficacy.

I-B. Integrative Value and Transformative Potential

Based on the nature of the research we are conducting, a multidisciplinary team is required in order to properly capture and analyze our results. We will engage expertise from the fields of CS, psychology, education, and cognitive science. If successful, our findings may greatly advance the field of CS education by identifying specific events or patterns which contribute to non-productive frustration events and loss of perceived self-efficacy, as well as offer a valuable set of observations, methods, and interpretations which may be applied to advance the pedagogical practices of other difficult fields of study. We will exhaustively explore the “Cognitive Processes in Realistic, Complex Environments” integrative research themes, in that we will gather and interpret data directly related to internal cognitive processes from the field, including observing many complex physical, social and educational interactions, both through our interviews and our recorded audio/video data.

II. Statement of Intellectual Merit

We seek to differentiate how student perceptions of frustration events result in either progression toward a solution, or regression into withdrawal, especially with respect to the long-term decision to withdraw from CS. We target our efforts specifically on CS education during the undergraduate years because of the perceived difficulty, exclusivity, and established norms associated with this field. All of these factors make positive reactions to failure so much more critical to a student’s eventual success. Young women in particular who are interested in CS may benefit greatly from failure resilience training, as research shows that they are more likely to abandon the field due to perceived failures (Katz et al., 2006). While our focus is on CS education, the lessons learned are applicable across all fields of academic instruction, creating more productive classrooms where students can learn from their failures and positively work through their frustrations. Indeed, further research suggests that we will positively influence not just academic success but also long-term happiness, health, and social interactions by teaching and reinforcing a positive failure model (Seligman et al., 2009).

V. Statement of Broader Impact / Broader Impact of the Proposed Work

Our research will have profoundly positive impacts on industry and society, as CS college graduates have been and continue to be a critical commodity through all aspects of our economy. If we can make participation in the CS field more attainable by the general population through integrating a positive failure model into existing pedagogy, then we can extend this knowledge to underrepresented demographics, enabling economic mobility by providing access to a highly lucrative and in-demand profession. The potential to shatter the stigmas associated with the perceived difficulty of CS present a massive incentive to develop ways to teach students how to cope with and learn from their failures while minimizing frustration and a desire to give-up, which we will accomplish by developing a positive failure model which can be integrated into a teaching curriculum.

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1. Objectives of this Research

Computer Science (CS) is one of the fastest growing fields, with more jobs available than qualified workers to fill them (Stevenson et al., 2005). If the United States is to remain competitive in the 21st century and beyond, universities must encourage and retain more CS students to complete their degree. While educational institutions have been somewhat successful at increasing the retention of underrepresented groups by separating novice programmers from experienced programmers in introductory courses (Hill, 2013), this is a shallow approach that does not address the core issues of retention, and a deeper, more cognition-centric intervention will prove more effective. To this end, we will investigate how the perceptions of inability, frustration and failure contribute to students deciding to leave the CS major.

One of life's greatest lessons is the knowledge that all success is predicated upon successful failures. As Thomas Edison mused, "I have not failed. I've just found 10,000 ways that won't work[1]." From Fox & Spector (1999), work-related frustrations can lead to a variety of counterproductive work behaviors, including aggression and withdrawal. Spector (1997) indicated links between frustration in the workplace and development of antisocial behaviors. Clearly, a delineation exists between frustration leading to progress (confrere Vygotsky, 1978), and frustration leading to aggression or withdrawal.

Opportunity for frustration events abounds in CS, as captured in the following citation: "Computer science is unusual among academic disciplines in that you can't succeed without getting past an unrelenting critic with exacting standards–the computer. A program compiles, or it doesn't. The program does exactly what you specified, not what you wanted or meant" (Guzdial, 2012). Personality types of those who stay in CS to become software engineers are strongly skewed (over 50% of the sample) toward four of the personality types identified by the Myers-Briggs Type Indicator (MBTI) assessment (Capretz, 2002). As Spector (1997) links frustration with antisocial behaviors, it is possible that people who persist in CS tend toward introversion in response to frustrations. People who leave CS may be those personality types who tend to aggression or withdrawal as a response to frustration. As such, healthy frustration response may be strongly correlated to increased likelihood for persistence.

Our objectives are to observe and analyze the specific frustration events that occur during the normal course of study of a typical CS curriculum, so that these events may be generalized and framed such that inflection points emerge in the student's perceived self-efficacy. For example, through observation we may discover that a particular assignment, exam, or course caused a negative frustration event in a significant percentage of our observed students. Through interviews, we may discover that a particular concept was not well instructed, was possibly outside of the student's learning capabilities based on descriptions of their difficulties (Vygotsky, 1978), or we may identify other factors which we are unable to anticipate at this stage. Additionally, we may have a direct effect on the student's perceived self-efficacy based on failure events simply by virtue of the fact that our research is forcing them to evaluate failure metacognitively, while providing an ad-hoc social network (Volet, 1991). By identifying specific, commonly occurring failures within our experimental group and analysing the "state" of the subject while he or she was experiencing this failure, we hope to identify emergent patterns which may allow us to recommend modifications or extensions to existing CS pedagogical practices, with the end result that more students are retained and succeed in completing their degree.

[1] http://www.brainyquote.com/quotes/quotes/t/thomasaed132683.html

2. Integrative Strategy

Based on the nature of the research we are conducting, a multidisciplinary team is required in order to properly capture, analyze, and interpret our results. The main focus of our research is the examination of individual reactions to failure events in CS, including facial expressions and recorded audio, as well as the subsequent perceived changes in self-efficacy. Properly interpreting these factors requires a robust source of knowledge and expertise from the fields of CS, psychology, education, and cognitive science. We assume inherent risks in asking a large group of CS freshmen to consent to high levels of video and audio surveillance, especially during frustrating and possibly emotionally-charged failure events. To our knowledge, no such study probing the specific external failure reactions (frustration events such as compiler errors or negative assessments on exams) and their subsequent correlation or causation of internal failure events (a student deciding to withdraw from a major) has been attempted. Most disciplinary approaches focus on external events, while positing that internal events are “too difficult” to examine, due to their inherently subjective nature (Kinnunen and Simon, 2010). If successful, we may greatly advance the field of CS education by identifying specific events or patterns which contribute to non-productive failure events and loss of perceived self-efficacy, as well as offer a valuable set of observations, methods, and interpretations which may be applied to advance the pedagogical practices of other difficult fields of study. We will exhaustively explore the “Cognitive Processes in Realistic, Complex Environments” integrative research theme, in that we will gather and interpret data directly related to internal cognitive processes from the field, including observing many complex physical, social, and educational interactions, both through our interviews and our recorded audio/video data. Our diverse team of researchers brings together experts from CS, psychology, education, and cognitive science with diverse backgrounds.

3. Motivating theory and evidence:

To present theory and evidence which motivates our project, we first establish defining terminology for a frustration event and withdrawal. We identify key theories about frustration and its potential role as both a helpful factor and a harmful factor in learning. We ground these theories by considering ways in which they appear in practice in the CS classroom,culminating in our conceptual framework. We include a discussion of study methods for working on frustration events and withdrawal, as well as include alternative methods which we expect to be efficacious in our proposed study.

3a. Terminology

Various terms arise across studies to capture the concept of frustration. Spector (1997) uses “frustration” as an ambiguous, general term describing dissatisfaction in the workplace. Papert (2002) struggles to identify a specific term, but resorts to “hard fun”, to capture the feeling of satisfaction which arises through perseverance through the frustration. Pea (1986) discusses bugs as pervasive conceptual misunderstandings, and attempts to identify an overarching umbrella “super bug” as the key misunderstanding students encounter, but doesn’t use any other term for the obstacle that is a bug in a computer program in his discussions. Kinnunen & Simon (2011) refer to “struggles”, but focus more on perceptions of self-efficacy than on the struggles themselves. Krebs (2012) speaks of CS from the point of view of an outsider, but considers every compiler error to be a “failure”. Kapur (2008) also uses “failure”, but does so in targeting ways that a failure state can lead to deeper conceptual understanding. Guzdial (2012) uses “failure” and “struggle”. Paul (2012) refers to the struggle with conceptual understanding as “floundering”. In short, there is no consistency of terminology!

Across all these terms, the common factor is a *short-term event*, such as a compiler error or a programming bug, which causes a student to pause in their progression until the event has been corrected or resolved. For purposes of our discussion, we refer to the short-term event of being blocked in progress as a **frustration event**.

Separate from frustration events are the larger decision points where someone resorts to withdrawing from the field of CS altogether. Katz et al. (2005) refer to those who stay as “persisters”. Beaubouef and Mason (2006) focus on “graduates” and “leavers”. Biggers et al. (2008) refers to “CS graduates” and “CS leavers”. We use the term **withdrawal** as defined by Spector (1997), as this is a culminating outcome in response to a sufficient amount of frustration. Our study seeks to identify in what ways frustration events contribute to the decision to withdraw.

3b. Theory of Frustration - Helpful and Harmful

Vygotsky (1978 translation) introduced the concept of the Zone of Proximal Development (ZPD), as the range of skills which an individual learner is capable of reaching with assistance from a “more-knowledgeable other” - in other words, learning is optimal when the individual is engaged in activities outside their skill set, which engenders frustration. In practice, ZPD would have students engage in activities for which their current knowledge and skill set is inadequate for them to succeed on their own. Vygotsky advocates educators to find the balance between activities which are clearly outside the individual learner’s zone, and activities which are already mastered by them. If learning activities are too challenging, the individual cannot engage, even with assistance; if already mastered, the individual can complete the task, but will not be learning as swiftly.

Deci (1975), in considering the role of challenge and frustration in motivation, discusses two basic drives: a drive to seek out challenge, and a separate drive to resolve challenge. Deci uses the term “cognitive dissonance” to describe a state in which an individual has multiple conflicting models or concepts which they are attempting to resolve. These internal drives to seek out and resolve challenges constitute Deci’s model of intrinsic motivation, and the balance between the two drives parallel Vygotsky’s concept of ZPD. If an individual feels that they are under-challenged, they will tend to seek out new challenges. If they are over-challenged, they will seek to resolve their current challenges, or withdraw from the conflicting concepts. In balancing the two drives, the individual finds progression in moving forward with their cognitive state.

According to Vygotsky, then, learning will be optimal when individuals have a healthy amount of frustration events, such that they are able to work through them with some assistance. From Deci, individuals will be motivated to seek out frustration events, as long as they are able to find paths toward resolution of those frustration events. If the cognitive dissonance becomes too great, however, the individual may lose their motivation, resulting in withdrawal.

Kapur (2008) investigated “productive failure”, which is focused on ways in which failure events may be more beneficial for effective student learning. From the study, students were either assisted in their group discussion by the instructor or teaching assistant (from Vygotsky, a “more-knowledgeable other”) to move toward the correct solution, or the students were left to “flounder” together in attempting to understand the problem. The floundering students outperformed the assisted students on later assessment of knowledge, which seems to stand as a counterargument to Vygotsky’s ZPD. The independent team spent more time failing to find a solution to the task, but did so with increased exploration of candidate solutions with problem critiques of proposals. Kapur claims that the time spent in the mode of productive failure contributed to these students performing better on the later assessment, because they had more exploration of class concepts and ideas. We might contend that the Kapur experiment was an inappropriate use of the instructor as a more-knowledgeable other because the instructor did not aid the student team in working through their frustration events in the most productive manner. However, the focus of both Vygotsky and Kapur is on the concept of students encountering frustration events as crucial parts of both learning (especially productive learning) and growing from the experience. Kapur’s study also indicates an increased correlation in student persistence versus frustration events when these frustration events are encountered in a social environment rather than in isolation.

3c. Theory in Practice: Frustration Events and Withdrawal in CS

With the background of Vygotsky's ZPD, Deci's counterbalancing drives of intrinsic motivation, and Kapur's example of productive failure offering benefit from exploration without a more-knowledgeable other, we look to studies of frustration events and withdrawal in the discipline of CS.

Meyer et al (1997) examines how students approach challenging mathematics problems in an elementary school classroom. They categorized the students into two different groups: "challenge seekers" and "challenge avoiders". The challenge seekers were better able to handle frustration and failure while maintaining a high self-efficacy about their mathematical ability. However the challenge avoiders were deterred by failure and less likely to think about the problems at a deeper level. These challenge problems were given in a project based mathematics class making their results particularly useful when studying students in CS. The categories identified also mirror the opposing drives proposed by Deci (1975).

Several studies focus on students who have completed their withdrawal from the CS discipline, and as such offer insights into recalled factors in the decision process:

Beaubouef and Mason (2005) list the following (among other factors) for student withdrawal:

1) Poorly designed CS1 lab courses (become debugging sessions for homework)
2) Lack of practice and feedback
3) Poor project management (students are unable to predict how long an assignment will take and proceed to coding too quickly)

Beaubouef and Mason indicate a variety of factors are at play in the ultimate decision to withdraw from CS. Our investigation will be informed by their findings, and will seek to validate or refute the findings reported. We are also open to discovering additional factors.

Biggers et al (2008) focused on the withdrawal decision, and the differences in withdrawing students from the ones who chose to persist, by asking both groups of students to describe the purpose of CS as a field. They found fundamental differences in the responses between CS graduates and CS leavers, including differences in the definition of the discipline of CS. From our interest in the reasons for deciding to withdraw, we find the ranked list of reasons fascinating. For women, some of the top reasons were "I did not feel as if I belonged" and "I am unhappy with my CS grades". For men, the top reason was "another career would be more fulfilling to me". Other reasons cited which might align with frustration events include "excessive workload", "CS classes were unfriendly", "overall curriculum was too difficult or too lengthy", and "poor teaching by CS faculty". The study did not specifically look for links between frustration events and the decision to withdraw, but does offer some insights into reasons cited by leavers after they have completed their withdrawal. Importantly, the sense of identity was a crucial factor for graduates in persisting. In addition, sense of identity was not only a missing factor for leavers, but was also a key factor in connecting with the community around their new major after transferring.

A drawback in studying students who have already transitioned through withdrawal from CS is that their recollection of their decision factors may not align perfectly with the real factors which directly contributed to the decision. This was noted in Kinnunen & Simon (2010) as a shortcoming in studying the role of frustration events. We discuss the approach taken by Kinnunen & Simon in section 3e in pushing the study observations closer to the point of student engagement with specific assignments.

Another vector of attack on student handling of frustration events is the examination of instructors in their role of crafting the education experience and in preparing their students for success. Cigman (2001) augments our theoretical foundation by examining the role instructors can play in helping students to build self esteem and confidence, often in the face of failure or frustration. These practices influence the student by presenting external beliefs and behaviors, as well as by offering students new interpretations of their own experiences and aptitudes. Cigman indicates that when failure occurs it should not be seen by the student as “I cannot”, but rather that “I did not”, with the differentiation between interpretations being especially difficult for children with low basic self-esteem.

More specifically in CS, a study conducted in 1991 involving CS university students investigated the possible merits of teaching metacognitive skills directly relevant to the subject matter. Students were regularly tutored alongside a standard introductory CS course, during which time they received instruction in a five-step general strategy for algorithm design and testing, techniques for modeling and coaching instructional techniques, and provided a collaborative social support structure. The results of this study indicated that the students who received the metacognitive intervention has a higher pass rate and a significantly higher average on test scores (Volet, 1991).

The work of Cigman and Volet lend credence to our expected outcome of identifying course obstacles, as well as identifying practices and characteristics of successful students, which could then be crafted into interventions. The resulting interventions could be considered by instructors as potential improvements to their pedagogical frameworks, in turn enabling their students to better cope with frustration events,with the end goal of curbing the undesired outcome of eventual withdrawal.

3d. Conceptual Framework:
With the theoretical background of the roles of frustration events and withdrawal now established, we lay out our conceptual framework in Figure 1. When students enroll in CS courses, they must be prepared to face challenges arising from the course projects and assignments. University instruction satisfies the drive to seek out challenges, but in so doing, new mental models are thrust onto students, causing cognitive dissonance which must then be resolved in order to allow for progression (Deci, 1975). Students commonly encounter problems that they cannot solve easily, entering into a cycle of frustration events. Our study focuses its analytical lens on observing those frustration events *in situ*, with triangulation of the occurrence of the frustration event to the student response, and to the eventual persistence or withdrawal of the individual.

We hypothesize that students who are able to successfully navigate these frustration events towards success in CS are able to do so because their frustration is mediated by such factors as operationalized knowledge, previous experiences, healthy social connections, and affective responses necessary to persevere. Even when these students cannot find direct assistance (such as through a more knowledgeable other, i.e. the instructor or a teaching assistant), they may be more successful at leveraging scaffolding around the assignment (Vygotsky, 1978), or they continue to make progress on the issue by themselves (Kapur, 2008). In contrast, we hypothesis that the students who ultimately decide to withdraw from the CS major lack some of the above characteristics, causing them to be unable to successfully navigate the frustration stage. When they are struggling in their CS courses or assignments they do not seek help, opting instead to remain isolated. The instructors are rarely able to directly observe individual students, causing the student to remain isolated and frustrated. We therefore expect that the student responses to frustration, mediated by their lack of knowledge, previous experiences, affective responses, isolation, and ultimately unconquerable challenges, will devolve into frustration and anger, eventually leading to the decision to withdraw from the CS major.

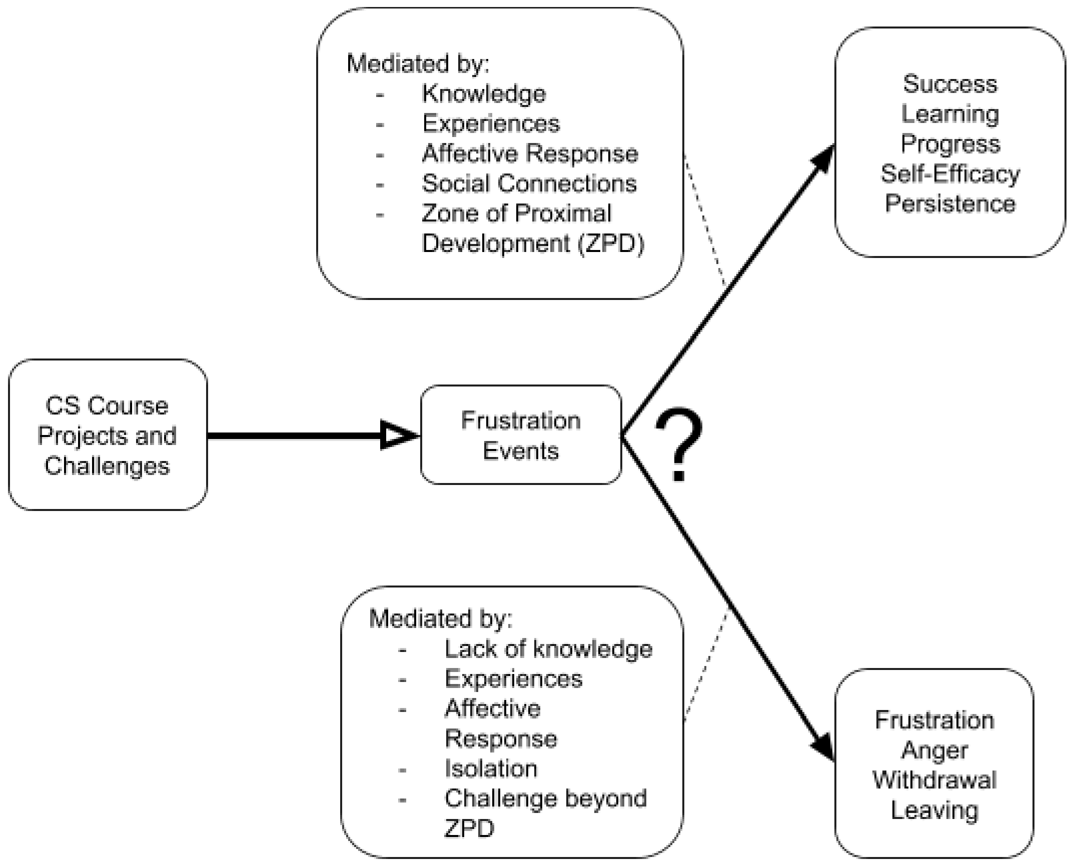

Figure 1: Our predicted outcomes of students' responses to frustration events.

3e. Studying Frustration Events and Withdrawal

As noted earlier, studies which focus on the withdrawal decision after it has been made have limitations in linking reasons cited with actual factors or events contributing to the decision. Kinnunen and Simon (2011) studied student perceptions within one to three days of a programming assignment. Even with the one-to-three day window, they indicate limitations to their study. They focus on their findings as representing student recollections after completion of the assignment, and are careful to not claim that these findings represent actual student experiences during the assignment.

Kinnunen & Simon examined student self-efficacy perceptions in an introductory CS course. They identified a particular group of interest in those who exhibited severe hindsight (i.e. they had successfully completed the program, but in the post-submission interview they presented with a negative self-efficacy through comparison with their supposedly brighter peers). Their study was completed in an introductory programming class taught in Media Computation. They hypothesize that similar patterns will emerge with more traditional introductory courses, but more investigation is necessary. Kinnunen and Simon note: "A weakness of our study lies in the lack of data triangulation. We only used students' interviews for this analysis. Additional observations of actual programming experiences would have provided an interesting comparison to students' remembered experiences. This would be an interesting subject for future work" (2011). Our proposed program targets this triangulation of observational data from programming experiences with student surveys to capture remembered experiences. Our inclusion of exit surveys supports triangulation of programming experiences to remembered experiences, and subsequently to the final decision to withdraw.

In an earlier publication by the same authors the focus was less on the theoretical underpinnings of student perceptions, and more on the actual methodologies and experiment design. Kinnunen and Simon (2010) specifically crafted their post-assignment surveys as moving the capture of individual perception to be closer to the assignment experience. Kinnunen and Simon previously had attempted a survey set at the end of the introductory CS course, and reported that the student perceptions were inconclusive and difficult to attribute to specific assignments or experiences. By transitioning to a post-assignment survey, which occurred within one-to-three days after the assignment, they felt that the survey more conclusively captured the student memories of the specific experience. Furthermore, in the 2010 publication, the authors note difficulties in more directly attempting to assess individual perceptions during the assignments. Some difficulties noted include:

1) Difficulty in assigning meaning to individual's experience by external observation alone
2) Disruption of task by asking individuals about their experience during the assignment
3) Difficulty in conducting observations because individuals complete assignments at diverse times and places

As a result, we find it interesting that Kinnunen and Simon (2011) indicate that triangulation across experiences during assignments with student recollections after the experience would be of benefit, while the same authors in (2010) indicate challenges to conducting the triangulation.

3f. Alternative Study Methods

We note several studies which attempt to conduct capture of student experience during computing assignments, despite the commentary from Kinnunen & Simon (2010, 2011) that such capture is challenging.

Baker et al. (2010) compared two categories of student emotion: frustration and confusion versus engaged concentration, delight, and surprise. They found that boredom was very persistent across learning environments, and was associated with poorer learning and problem behaviors such as gaming the system. They described as an observation technique the Baker-Rodrigo Observation Method Protocol (BROMP) for coding student emotions as they interact with the computer. With BROMP, the observers conduct their observations during the student engagement with programming activities, and capture their observations directly using the BROMP tool. As noted in Kinnunen and Simon (2010 & 2011), the assessment of emotional state by observers can be difficult to assess consistently.

Monkaresi et al. (manuscript) explore using computer vision techniques to detect engagement of students on a writing activity. Video is augmented with heart rate monitors and other sensors, and the authors construct supervised machine learning models to correlate the various sensor inputs into an affective measure. To combat the difficulty of an external observer assessing emotion, the authors capture engagement and affect during the writing assignment (by interrupting the participant), as well as by having the participant annotate their own video after the event. We see the use of video as a prompt to the participant in discerning their emotional responses during an activity, as opposed to Kinnunen & Simon's approach of asking the participant for their recollection after the activity has concluded.

The Monkaresi et al. study provides a foundation of using video to prompt participant recall, which they note as being comparable to the emotion capture through interruptions. Furthermore, their work supports the possibility of setting up a machine learning model to perform automated labeling of video footage. We see these innovations as strongly supporting our proposed study approach. The video capture techniques of Monkaresi et al. would offer rich data of the student experience, and would be triangulated with student recollection of their experiences through post-assignment surveys.

4. Research Questions:

In our research, we explore the effects of CS undergraduate students' experience with failure events on their continued perseverance in the CS discipline. Our intervention will focus on answering the following research questions:

> **RQ1:** What distinguishes frustration leading to progress (ZPD) from frustration resulting in withdrawal in early formative CS education experiences, especially with respect to underrepresented groups?
>
> **RQ2:** As we begin to develop and categorize frustration events, can these different categories model and predict variations in frustration reactions by individual differences such as gender, as well as persisting students versus those who choose to withdraw?
>
> **RQ3:** How do individuals who have decided to withdraw from a CS major describe factors which contribute to their decision?

Through these questions, we will understand why students find it difficult to learn CS, and how instructors might improve their teaching methodology in their class for greater learning success. Also, answering these questions will help us to directly combat the issue of high student withdrawal from the CS discipline.

5. Research Design:

We will explore how students experience failure and frustration in CS courses and how these experiences lead to either perseverance or withdrawal from CS. We plan to follow the incoming class of first year CS students for four years, specifically focusing on the required courses that make up the core curriculum of the CS degree. Namely, these courses include Intro to CS, Data Structures, Programming Languages, and Senior Projects. The participants must agree to be recorded via webcam while working on assignments toward these CS courses. Pre and post-surveys will be automated, offering a combination of quantitative questions with several open-ended qualitative questions. Through this process, we will collect data to support triangulated analysis, constructing meaningful connections between frustration events and the decision to withdraw from CS. We will examine these effects in both a narrow scope (through post assignment and exam checkins) and in a broad scope (through pre/post class checkins) in order to track how frustration events influence the decision to withdraw from CS. In addition to the surveys about student attitude toward CS, we will also conduct recorded observations of students working on the course in both classroom settings and in the more informal setting of the CS Educational Laboratory (CSEL) where students receive help from peer tutors and other students in the course. For the cohort of first year students, we will conduct individual interviews for those who consent to participate in our study as they begin their first CS course, as well as exit interviews when they either leave the major or graduate. We outline our research questions and methodologies in Table 1.

Research Questions	Methods	Data

RQ1. Frustration: Progress or withdrawal, identify factors: - Categorize Factors - w.r.t. Gender - w.r.t. Under-represented Groups	- Observations - Pre/post survey on self-efficacy, affect toward CS - Exit interview	Observation Notes Survey responses Interview transcripts
RQ2. Individual reaction to Failure Events - Meta-cog skills - Gender - Response - Learning styles	Post assignment - Quick survey (self-checks) - Social, how frustrating, how surviving	Survey responses
RQ3. Factors in decision to withdraw	- Pre-major Interview - Exit interview - Reflection - Draw out factors that motivated decision to leave	Interview transcripts Timeline construction triangulating factors across academic career to decision point

Table 1: Research Questions, Methods, and Data Collections: We highlight each overarching research question with the research methods we will use to collect data to answer these questions.

Through these research questions, methods and data collections (Table 1), we gather and analyze data in order to understand the main factors which students consider in deciding to leave the CS major. Analysis may inform instructor modification of their teaching methods, or may help students toward success in the CS major. As Winslow & Rosalind (2004) remarked, “Since failure, over and over and over again, is a prerequisite to becoming an expert, so too is the ability to persevere and remain motivated through failure”. We believe that these research questions, methods and data collections (Table 1) will enable us to understand and help students to deal with frustration events, with the direct result of improving long-term retention.

5a. Observation Technique

With consent, our subjects will be monitored consistently throughout key core courses in the four-year CS curriculum, including but not limited to classroom activities, graded events, projects, homework assignments, and study groups. This will be accomplished through the use of video recordings of recitations, office hours, and the CSEL as well as personal video capture through the use of a webcam. We will use the BROMP observation protocol to code the emotions expressed by students in the group videos and use student interviews to characterize the emotions from the webcams. From these two characterizations we will develop a machine learning program to help code the emotions of students while they program. We will identify trends from the surveys and interviews with the observations in order to develop a complete understanding of how different students react to failure events, and how these different reactions influence students to either persevere or leave the CS field.

5b. Survey

We will administer two types of surveys:

1. **Pre/Post-course survey**: Measures self-efficacy in CS and how students are currently feeling about pursuing a CS degree. Includes some example questions which will be graded on a Likert-type scale. For example:
    a. This course helped me gain confidence in my CS ability

    b. I feel confident in my ability to complete a degree in CS.
    c. I feel that I am valued member of the CS community at the University of Colorado.
2. **Post-assignment survey**: Measures self-efficacy in CS immediately after completing a programming assignment. Also includes some example questions which will be graded on a Likert-type scale, as described above.

5c. Interview

We will conduct two types of interviews:

1. **Event Interviews:** After our team identifies a student's potentially illuminating frustration event, we will conduct a perceived self-efficacy interview similar to the work done by Kinnunen and Simon (2011). After this initial interview, we will review the previously recorded footage with the student in order to elicit their actual emotional state while they were working on the course. We hope to make connections between their remembered emotions and their actual emotions, potentially highlighting an existing cognitive dissonance and potentially scaffolding metacognitive evaluation skills
2. **Entry/Exit Interviews:** We will conduct lengthy entry and exit interviews with each student who has agreed to participate in our study in order to identify the underlying reasoning behind their choice to leave the CS major or why they persevered through to graduation. Some example questions we will potentially ask them include:
    a. Describe your feelings about (earning a CS degree or leaving the CS major).
    b. What factors contributed to the decision to leave the CS major?
        i. What might have mitigated each factor?
    c. What factors contributed to your success in completing the CS major?

5d. Monitoring Project Performance

A project advisory board will be instantiated with representatives from CS, psychology, education, and cognitive science. We have received commitment from the department chair of each academic department, and from the director of the Institute of Cognitive Science, to appoint a faculty member in good standing to take part in the advisory board. In addition, at the first meeting, the advisory board will extend invitations to two individuals from outside the university, to provide an impartial view on the work being performed. This advisory board will convene at least once per calendar year to receive a status report on project performance and findings to date, with a review of current project risks. In addition to the advisory board, this study will be conducted under periodic review by the university Institutional Review Board (IRB). We will quantify our research performance using student pass/fail statistical data as follows: Based on mandatory faculty course-end questionnaires at CU Boulder, 906 freshmen enrolled in CSCI 1300: Introduction to CS. We can reasonably expect a similar number for 2016. Our study group of 30 students will be benchmarked throughout the four mandatory classes, namely Intro to CS, Data Structures, Programming Languages, and Senior Projects by examining the drop rate of our group from each class, as well as overall drop rates of the student cohort at each class. The drop rate comparison data will allow us to capture whether participation in this study has shifted student outcomes, either by increasing persistence or increasing rate of withdrawal. In the latter stages of the study, as interventions are proposed, the drop rate comparison will inform whether the intervention has any impact. Additionally, we will assess through our exit interviews the reasons for student withdrawal from either the CS field of study, or our experiment, and modify our methods as necessary.

5e. Project Timeline

- **Year 1**

  The first year will involve recruiting students to participate in our study and developing our survey and interview questions as well as the frustration recognition tool. The recruitment phase will take place during the first two weeks of the fall semester. After we have our subjects, we will begin our experiments. During the first year, we will refine our survey and interview questions, continue development of the frustration recognition tool, and the subjects will complete the introductory CS courses.

- **Year 2**
  After the completion of the first year, we will report preliminary results from the introductory courses to our advisory board. We expect to gain insight from these initial results since they involve the introductory courses. We will continue the experiment into the student's sophomore year and continue development of the frustration recognition tool.
- **Year 3**
  After the conclusion of the second year, we will report our initial findings to the advisory board, including any patterns we have seen and make preliminary recommendations about mediation factors in frustration that have allowed certain students to be successful in the major. We will also prepare our first report specifically about frustration and failure in the introductory computer science courses. We will reassess our sample size to make sure we have enough students remaining in our study. We will continue the experiment into the student's junior year and complete development of the frustration recognition tool.
- **Year 4**
  After the conclusion of the third year, we will report our results to the advisory board along with more detailed recommendations for frustration mediation techniques that can be used in the courses and department. We will complete the study during the fourth year and refine the frustration recognition tool. At the conclusion of the study, we will share our complete findings with our advisory board and write a detailed report of our findings and recommendations for mediating frustration leading to failure and withdrawal from CS including individual stories of success and failure.

5f. Dissemination of Results

The presentation of our results will proceed in a two-step process. First, we will share our findings with the relevant departments at the University of Colorado, and subsequently to other R1 Institutions. By sharing the results with these communities, we hope that CS departments can understand and address some of the negative frustration events and increase the retention and success of CS students. At the University of Colorado, we would share our results with the ATLAS department as they are actively working to develop their own introductory CS curriculum. Our research findings could very likely hold true across other STEM disciplines as well, motivating our outreach to interdisciplinary departments on campus such as the Institute of Cognitive Science. In terms of publication, we anticipate SIGCSE and ICER as potential conference venues for the results. We plan to publish intermediate results about the initial findings in the introductory CS courses, followed by the final results from the full study.

5g. Risk, Reward, and Risk Management

Below we address some of the issues that we anticipate might arise and pose a risk to the results of the study.

- **Recruiting and retaining sufficient students:**

  To recruit students to the study, we will offer a (yet to be determined) compensation. We will also emphasize that by participating they will have a lasting impact on the educational philosophies of the CS department. To address some of the security and privacy risk of being recorded while working, we will highlight how we will use their data (specifically, anonymity of results and security measures we will take to protect their information). All policies for gathering, retaining, analyzing, and securing participant data will be heavily reviewed through the university Institutional Review Board (IRB) as a study on human subjects. Another potential issue is retaining enough students in the study to make meaningful conclusions about frustration in upper level CS courses. If our sample size has become too small once we reach years three and four, we will recruit additional students from those upper level classes who were not originally in our study.

- **Collecting and analyzing large amounts of data:**
  We will mitigate this risk by extending research opportunities to students across the undergraduate community to help with the data processing and analysis. To recruit them, we will emphasize that participating in this data analysis will help improve the CS department and give them the power to make a lasting impact. Recruitment of student researchers will be pursued across all majors, especially focusing on psychology, education, and cognitive science.
- **Observer Effect:**
  Since this is a long term study, we hypothesize that the students' behavior while working may initially be different because of the observations. As the study progresses, we anticipate that the camera will become a usual part of the working process and no longer a significant factor of student consideration.
- **Unanticipated Risks:**
  Risk management will be an ongoing practice for the research study team. We will rely on our extremely capable advisory board to help us handle other issues that arise during the study by including risk reporting at all advisory board meetings.

While the study does have some potential issues that could lessen the impact of our results, we believe the reward outweighs these risks. This study promises a profound impact on undergraduate CS education. The results could provide insight into how to retain students and change the CS community to be a more welcoming, inclusive group, helping create a more diverse field of computer scientists to fill the increasing number of jobs related to computing.

6. Data Analysis:
The gathered data provides a corpus of observation notes from lab sessions, survey responses, and interview transcripts. In support of RQ1, analysis will consist of categorizing frustration events from observation notes and survey responses. Analysis in support of RQ2 will consist of categorizing responses to frustration events from survey responses, with an eye toward metacognitive skills being employed. Analysis in support of RQ3 will result in construction of timelines for each student who has decided to leave the CS major, or has reached graduation. To accomplish this, participants in the study will be triangulated across the corpus by a participant identifier. Thus, as each participant interacts with the research team in any fashion, including observations, surveys, and interviews, those interactions will be recorded against the participant identifier.

The constructed timeline for each student will provide a rich data set describing events from specific assignments and labs, to lab work, to classes, culminating in either completion of the program or a decision to withdraw. As each timeline is constructed, correlations among timelines will be studied for consistencies and dissimilarities. Specifically, we are looking for a relation between frustration events building and culminating in a decision to withdraw (RQ1 and RQ3), as well as relations between frustration events and metacognitive skills to mitigate their impact (RQ2). In addition, we are seeking other factors beyond frustration events which may be contributing to the decision to withdraw (RQ3). We are specifically interested in seeing if these factors can be observed in all courses or at certain points within a course. This will enable faculty to be especially observant during these time periods to prevent an increase in frustration.

As well as examining overall trends, we are also interested in differences in the frustration events leading to withdrawal among women and underrepresented minorities (RQ1) and how the these groups cope with frustration and failure events (RQ2). We hypothesize that the critical points which lead to withdrawal may be different for these groups.

Margolis & Fisher (2003) noted in their investigation into students deciding to withdraw from CS as a major that students tended to cite a lack of interest in the field, which led them to the decision to withdraw to pursue something which they were interested in. The study went deeper, and identified a consistent correlation of a reduction in confidence preceding the loss of interest. We anticipate that the loss of confidence may be influenced by frustration events. Based on the work of Margolis & Fisher, we expect that the information provided at the time of the exit interviews will be inadequate on their own to identify the root causes of the decision to withdraw. Thus, we anticipate needing the richer data corpus of all interactions with the student from their initial entry into the CS program in order to truly uncover the impact of frustration events and other factors in the decision to withdraw.

7. Team composition:
The research agenda outlined here builds on and is motivated by the prior work of our investigative team:

> **Parker** (PI) offers a strong background fusing theoretical CS with practical Software Engineering practices, including software project management education and experience. This background offers a solid building point for Parker's research interests into CS education. Previous research work includes the transition of students from a university setting to industry. This work offers opportunity to more rigorously investigate challenges which face individuals who are adequately motivated to enroll in a CS education program, but may lack the skills needed to persist in the field long enough to become established.
>
> **Gendreau** (Co-PI) is interested in developing new and improving existing programming languages and software for teaching students to code. Gendreau brings a solid background in CS education across multiple institutions, with her international research experience in programming languages and algorithms. This unique blend allows Gendreau to grasp insights into the learning experience and long-term challenges which exist for students across a diverse and divergent spectrum.
>
> **Chamberlin** (Co-PI) as a military officer is skilled in teaching and applying both the practical elements of CS to solve complex, real-world problems and their underlying theoretical frameworks. He has worked closely with government agencies responsible for cyber security at a national level, and is familiar with their practices involving generating interest in defensive applications of CS. He is interested in applying his knowledge and experience to generating a curriculum that will both generate interest in CS and make the field more accessible to those interested.
>
> **Lu** (Co-PI) brings experience with web programming and focus on test case design, performance testing, and automated tool development, with a strong focus on application of software development practices and requirements elicitation. From this background, Lu turns to the educational aspects of CS, with strong interest in seeing everyone succeed at moving forward in their understanding of CS as a field, and in their capacity to perform software engineering in particular.
>
> **EDUC** (Co-PI) offers a complete background in pedagogical practices with respect to establishing an educational program. EDUC directs the layout of our course, with insight into approaches for

integrating activity-based learning opportunities, student-led instruction, and other sound pedagogical practices, to craft a successful course offer.

PSYC (Co-PI) brings an understanding of affective responses to frustration and failure. PSYC offers an analysis framework through which we will monitor for frustration, and build our model of differentiating negative frustration responses (withdrawal and failure) from positive frustration responses (persistence and eventual triumph).

COGSCI (Co-PI) Allows for the thorough investigation of how the facial expressions, recorded audio clips and interviews of our subjects reflect the underlying cognitive processes that are associated with failure and self-efficacy.

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