Developing Software Engineers: Investigating the Influence of a Computer Science Capstone on Professional Identity Formation

by

Richard J. Parker

B.S., Brigham Young University, 2002

M.S., Colorado School of Mines, 2004

M.S., University of Texas San Antonio, 2010

M.S., University of Colorado Boulder, 2018

A thesis submitted to the

Faculty of the Graduate School of the

University of Colorado in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

Department of Computer Science and Institute of Cognitive Science

2019

This thesis entitled:
Developing Software Engineers: Investigating the Influence of a Computer Science Capstone on
Professional Identity Formation
written by Richard J. Parker
has been approved for the Department of Computer Science and Institute of Cognitive Science

_____
Professor Tamara R. Sumner

_____
Professor William R. Penuell

_____
Professor Clayton H. Lewis

_____
Professor Lecia J. Barker

_____
Professor R. Benjamin Shapiro

Date _____

The final copy of this thesis has been examined by the signatories, and we find that both the
content and the form meet acceptable presentation standards of scholarly work in the above
mentioned discipline.

IRB protocol #15-0224

Parker, Richard J. (Ph.D., Computer Science and Cognitive Science)

Developing Software Engineers: Investigating the Influence of a Computer Science Capstone on
Professional Identity Formation

Thesis directed by Professor Tamara R. Sumner

Professional identity, or the connection between individuals and their professional community of practice, begins forming as early as deciding a major for university studies. Development is supported or hindered by situated practices and experiences throughout undergraduate studies and across the transition from university to the workplace. To explore how the academic setting supports or hinders professional identity formation, I expand situated learning theory with stages of concern to directly model identity-related progression of concerns across situated planes of development.

My dissertation research focuses on the Computer Science (CS) capstone experience. The CS capstone course is composed of teams of four to six undergraduate CS students. Each team works directly with an external sponsor to apply software engineering practices toward a project with real-world impact. I conducted interviews with 19 students across two cohorts of the capstone course, and gathered individual and team artifacts from five cohorts of the course. Analysis of this qualitative dataset explores the role of emotions and interest in supporting student engagement and perception of project relevance. These findings culminated in my proposed framework, Multiple Planes of Concern or MPoC, which combines planes of development with stages of concern for examining support for professional identity formation in an academic setting.

This dissertation is organized around three publications over the course of my studies. Outcomes from this dissertation research include the MPoC analytical framework, a conjecture map linking the CS capstone structure to learning theory, broader implications for educational support of professional identity, the CS Capstone Dataset, and the academic artifact consent policy. I advance theory at the intersection of learning sciences and formation of professional identity in CS.

Dedication

To those who doubt their place in a community,

with hope to create opportunities for meaningful connection,

support deeper identity formation,

and share the building of a world for all.

Acknowledgements

I am indebted to my advisor, Tammy Sumner, for accepting me into her flock of Computer Science Education researchers. Her guidance and mentorship have been especially meaningful, as this dissertation research pushes the boundaries of our shared experience and knowledge. Thank you for supporting me through my research apprenticeship!

I am grateful to each member of my committee for sharing your perspectives and insights, through which you have tempered, strengthened, and shaped my work. The outcomes are beyond what I could have attained without you.

Thank you to each member of the Sumner Research Group for many inspiring theoretical discussions and exploration of this space between Computer and Cognitive Sciences. I am especially grateful for the assistance with thematic analysis and reading preliminary drafts.

I appreciate my undergraduate research assistants Avery Olson, Teresa Lim, and Ann Ngo, who helped shape the thematic analysis process while listening to my burbling attempts to express the conflux of theories that underpin this work.

I am grateful to the five cohorts of capstone students who shared their project experience with me. I am convinced that you were are already capable of the next stage of your careers; the project experience served to buoy up your confidence and ignited your inner drive to go on into your professions. Thank you for inspiring my studies into this capstone crucible.

Finally, and most especially, thank you to Desi Parker for her eternal support and encouragement! You shared the burdens of this journey, all the struggles and challenges, and still believe in me.

Contents

Tables

Table

Chapter 1

Traveling the Professional Path in Computer Science

1.1   Parable

> Three travelers passed through a forest along a trail, where a tree had fallen across the path. The first traveler labored to climb over the tree, then continued on their journey. The second traveler worked to clear the path by moving the tree aside, then continued on their journey. The third traveler dragged the tree farther along the trail, to an impassable ravine. There, the third traveler fashioned a bridge and opened a new realm of possible destinations.
>
> Which traveler journeyed best? Perhaps each accomplished what they could, with what they had to offer. *[Anonymous]*

This parable of three travelers highlights the differences in capacity for influencing and changing the world around each traveler, and suggests concerns each was able to focus on. The first traveler worked their own way through and forward, taking care of *self*-oriented concerns and immediate needs while struggling over obstacles. The second traveler addressed the *task* at hand, improving conditions for future travelers passing through the same obstacles. The third traveler looked beyond the current tasks for opportunities to build bridges, broadening the *outcome* of new destinations available to all.

Three travelers, working within their current capacity of concerns. Each exemplifies and introduces one of the three Stages of Concern [38], namely *self-*, *task-*, and *outcome*-oriented concerns. I apply the Stages of Concern model to studying *professional identity* (PI) formation in undergraduate Computer Science (CS) education.

My work investigates how the professional experience of a CS capstone in software engineering does or does not influence PI formation for undergraduate CS students. My central research

question is: **what is the influence of a CS capstone course on undergraduate development of professional identity during the university-to-work transition?** This research is investigative in nature, exploring the interplay between professional experience with collaborative teams in the CS capstone course and the role of academic support for PI formation.

1.2 Professional Identity Formation

Professional Identity (PI) is the sense of connection between an individual and a professional community of practice. "A professional identity is critical to a person's sense of self: It is about connecting with roles, responsibilities, values, and ethical standards unique to a specific profession" [41]. For people who are in an academic space, as in a university setting, PI begins forming as early as the decision of a major [48]. The transition from university to work offers students opportunities to move forward within a profession, though not all make the transition smoothly [25, 93]. The resulting "identity crisis" [31] accompanying delayed or impaired PI formation may appear as a lack of belonging [9], as job search frustration from a long duration of hunting or outright failure to find a position after graduation [90], or by failure to persist in a position [83]. "While [students'] development to professionals is of crucial importance to a student's later professional advancement, [professional development is] often addressed in only a rudimentary form within the curriculum" [60]. Inadequate PI formation may culminate with individuals deciding to withdraw from their professional aspirations, despite having completed the necessary academic preparations for the field [9, 76].

The process of forming an identity may occur subconsciously when progressing naturally, rising to a conscious awareness when frustrated or explicitly called into focus [31]. Studies of PI formation across psychology and political science students [61], social workers [97], and CS students [89] all used semi-structured interviews to guide participants in reflecting on their definitions and experiences of PI. One study left PI as a "black box" for participants to fill with their personal conceptualization of what they were becoming professionally, then asked about level of confidence on a scale from first-day student to first-day practitioner [25].

A study on bankers found a correlation between dishonesty and activated PI [21]. To activate or prime the PI of bankers, the researchers posed questions about where participants worked and day-to-day job activities; the control group received questions irrelevant to their professional activities, such as amount of home TV viewing [21]. The bankers study is of value because it demonstrated influence from PI through questions about the professional context and behaviors occurring with specific roles in that setting.

Learning theories emphasize identity as occurring alongside situated development, as a byproduct of the learning process [53, 79, 91]. Learners adopt practices that are legitimate to a community of professional practice, accompanying the formation of PI [53, 95]. Situated Learning focuses on development as an observable change in the ways of participating [78, 79]. I examine PI formation from a situational perspective, building on and extending Situated Learning theories in this area.

The role of conflict or tension as a driving pressure for PI formation occurs as a consistent thread across theories, despite different terminology applied. For early identity theory, this is *identity crisis*, or a feeling of discord or dissatisfaction with one's stage of identity [31]. With communities of practice, this is *tension* which is personally experienced across the *nexus of multi-membership* of all communities to which the individual connects [95]. The experienced tensions may or may not ever be fully resolved, but the work of seeking resolution gives rise to identity as the individual decides what is meaningful and how to balance the tension across community boundaries [95].

1.2.1   Emotions of PI Formation

Emotions are important in accompanying the PI formation process. Building on identity formation as a subconscious process, Erikson notes:

> We are thus most aware of our identity when we are just about to gain it and when we ... are somewhat surprised to make its acquaintance; or again, when we are just about to enter a crisis and feel the encroachment of identity confusion....
> An optimal sense of identity, on the other hand, is experienced merely as a sense of psychosocial well-being. Its most obvious concomitants are a feeling of being

at home in one's body, a sense of 'knowing where one is going,' and an inner assuredness of anticipated recognition from those who count [31, p. 165].

This duality of emotional responses linked to the process of identity formation, both when it is progressing and when stymied, is similarly described by Burke [13]: "When the discrepancy between identity relevant perceptions and the identity standard is small or decreasing, people feel good. When the discrepancy is large or increasing, people feel bad or distressed [13]." The author notes positive outcomes of identity formation as including "the production of self-worth, self-efficacy, and feelings of authenticity", while negative outcomes include "persons become distressed, angry, and depressed" [13].

In terms of resolving tensions across community boundaries:

> The experience of multimembership can require the reconciliation of a nexus that is unique and thus very personal.... The careful weaving of this nexus of multimembership into an identity can therefore be a very private achievement. By incorporating into the definition of the person the diversity of the social world, the social notion of a nexus of multimembership thus introduces into the concept of identity a deeply personal dimension of individuality [95, p. 161].

From development of PI for pre- and in-service teachers, researchers considered *concerns* as both an expression of PI and a drive for changing behaviors and PI: "The arousal and resolution of concerns is a highly personal process that takes time and timely interventions of both cognitive and affective natures" [59].

Tension underpins and drives the partly-subconscious, emotional, and personal process of identity formation. Study of these pressures can inform analysis of the larger identity formation process.

The role of emotions in the PI formation process may be minimized or overlooked by educators in crafting classroom experiences, especially in CS [34]. Another CS research team investigating persistence during undergraduate CS education noted:

> When the interaction of culture and individual attributes leads novices to feel not only confused, foolish, and unable to control consequences of their behavior, but also trapped in a situation where they must continue to experience those feelings,

then negative socialization outcomes will ensue - anger or withdrawal. Anger leads to intransigence or active rejection of the values of the socializing agents. The angry novice says, 'These people are so crazy that only an idiot would want to act like them' [87].

Considering emotions as a factor in PI formation builds to my first research question:

RQ1: What role does emotion play in influencing engagement and professional identity formation in a CS capstone course?

RQ1 examines qualitative data from student interpretations of their experiences with the CS capstone course under investigation. Reflection offers participants an opportunity to recall and to explore their (potentially) subconscious reactions to their experiences in the CS capstone projects. The interview script (see Appendix A) specifically asks students how they *feel* about their project outcomes. By phrasing the interview questions in this manner, respondents may surface their internal emotional recollections about the experience. The resulting transcriptions offer insights into emotional state and affective reactions to experiences, with tie-ins to engagement and PI formation. "Professional identity may have a lot to do with whether [professionals] survive and thrive in a profession. More than just inspiration, professional identity formation ... is increasingly seen as a crucible in which [professionals] become tempered against burnout, cynicism, and ethical decay" [64].

1.2.2   From Emotions of Concern toward Interest and Relevance

My investigation into affective responses from student interviews with RQ1 revolves primarily around statements of *confidence* and *concern* as opposing expressions of a similar response. From *Unlocking the Clubhouse*, research into CS retention identified confidence and interest as intertwined expressions from students in exit surveys [55]. Building on findings about *confidence* as a stronger indicator than *ability* for predicting persistence in engineering disciplines [85], *Clubhouse* noted withdrawers who described a loss of interest accompanying their loss of confidence, both contributing to the decision to withdraw [55].

Building on RQ1's focus on emotions of *confidence* and *concern*, I examine the Stages of Concern model [38], introduced earlier with the travelers parable, for CS education. CS undergraduates experience three types of concerns or shortcomings during their PI formation process.

First, around self-oriented concerns, are "conflicts they experience in the social and cultural conditions encountered in these fields" [32]. As an example, internships place students into the existing culture of the engineering professions, and may contribute to gender stereotype enculturation [84]. Also within self-oriented concerns are professional role confidence, where individuals might doubt their "ability to successfully fill the roles, competencies, and identity features of a profession" [17]. Self-oriented concerns include "perceived fraudulence" or impostor syndrome [52, see also [18]].

The second type of shortcomings are individuals who struggle with task-oriented concerns, the mechanics of their chosen discipline. As with the *Clubhouse* findings of a connection between student confidence to perform and their expressed interest in their chosen discipline: when one is negatively impacted, the other may also fall, culminating in the decision to withdraw [55].

Third are those who look to the outcome-oriented nature of their studies. Again from *Clubhouse* [55], researchers noted gendered differences in expected use of a degree in CS.

> For most women students, the technical aspects of computing are interesting, but the study of computer science is made meaningful by its connections to other fields. [The sample of m]en are more likely to view their decision to study computer science as a 'no-brainer,' an extension of their hobby and lifelong passion for computing [55].

The same study noted that many women were interested in "connecting computing to other fields" [55]. These are examples of looking beyond the mechanics of CS toward an application or outcome.

When forming the CS capstone project teams, the course engages a practice of gathering student preferences as an indication of individual interests. This practice may support student engagement and connection with real-world relevance of the projects, contributing to a focus on *outcome*-oriented concerns. My second research question is:

RQ2: How does using student interest as the primary basis for forming teams

influence student experience in their capstone project?

RQ2 delves into the interplay between interest, engagement, and a sense of relevance, again drawing from the qualitative interview data as supported RQ1. RQ1 draws solely from end-of-project interviews, while RQ2 includes early-in-project interviews. These early interviews capture student perceptions closer to their preference decision points, while end-of-project interviews capture enduring perceptions.

1.2.3   Academic Support of PI Formation through Capstones

Bridging the integration of professional practice into academic coursework [8] is a method universities and colleges leverage for supporting PI formation. "Senior project or capstone-type courses ... provide student engineers the opportunity to solve real-world engineering projects, and have been highly regarded as important learning activities" [88]. Further, "capstone courses generally target undergraduate students who are nearing completion of their studies. They are designed to build on skills acquired in earlier courses and emphasize situations and challenges that exist in the real world" [77, in [28]].

In a 2015 nationwide survey of engineering capstone courses, 256 institutions provided details about their implementation of "a culminating design experience" [47]. Generally, capstones are widely varied in how they are conducted, yet tend to focus on authentic professional practices supported by the university; collaboration in a team setting; and meeting real-world objectives [47]. Capstones generally run one (31%) or two (55%) semesters with an external project sponsor (70%) [47].

A separate survey aggregated literature specific to CS capstone programs [28]. The first publication advocating for a CS capstone is from 1972 [71]. Again, specific implementation details for CS capstone programs vary widely across the nation [28]. The authors of the literature review noted few publications integrate theories of learning, and "virtually all of the learning theories discussed in the capstone course literature were some form of constructivism" [28], including Situated

Learning [2].

Ben-Ari explores potential for using Situated Learning as a model for CS education, and concludes that it is inadequate [7]. A key shortcoming noted is that, because graduates of CS programs proceed into a diverse range of career trajectories [60, 69], it is impossible to create a fully legitimate and authentic learning experience in the university setting that sustains all potential career paths [7]. In a subsequent publication, Ben-Ari offered an alternative theory, termed Fertile Zones of Cultural Encounter (FZCE), whereby a cultural bridging experience is created by embedding a professional space within the academic classroom [8]. I see CS capstone programs as an example of a bridged FZCE learning experience, where students are exposed to opportunities for professional encounter while still shielded in the academic setting. Within the same space, external project sponsors accept that the experience is first and foremost a learning opportunity while still supporting potential progress on real-world problems.

As part of my exploration of the foundation of the CS capstone course instantiation that is the context for this dissertation research, I inquired into the early motivations for launching the course in the 1987-88 academic year (AY). The department chair at the time recalls:

> After I moved to Colorado, the Department was founded. I was chair and in a few years I did seek out connections with local industry. This [was] to get advice and to let them know that we existed. Somehow or other this evolved into my wanting our students to have practical experience. A senior program that was as close as possible to what they might face seemed like the right thing and it certainly would not hurt the ones who planned to go on to graduate school. So, we founded the Senior Projects [capstone] course. The ties between Academe and Industry are hard to understand. I feel there should be close ties because most students end up in Industry and it is important for all students to understand the realities of life [33].

While some implementation details have continued to evolve over the years since this CS capstone course was first launched, this core vision still carries the program forward [80].

CS education and the CS capstone solidly align with a situated learning model: "We believe that computing is more than a set of skills. It is embedded in a social system consisting of shared values and norms, a special vocabulary and humor, status and prestige ordering, and differentiation

of members from nonmembers. In short, it is a culture [50]." The capstone experience gives students "broad access to arenas of mature practice" [53, p. 110].

1.2.4 Building toward a Situated Identity Model

Although *identity* is acknowledged as accompanying development within Situated Learning [91], the core focus often is placed on changing ways of participation [53]. Alternatively, Fuller's Teacher Concerns Model [38] offers a model of maturation accompanying formation of PI. My proposed method of combining Rogoff's Multiple Planes of Development with Fuller's Teacher Concerns Model yields a framework of stages of concern across planes of development.

I propose Multiple Planes of Concern (MPoC) as a method for exploring the process of forming PI in a situated learning context. It expands Rogoff's Multiple Planes of Development analytical model, which is a situated learning approach for considering development as occurring simultaneously across personal, interpersonal, and community planes [78]. The original model offers flexibility in application, supporting research into any situated development process. I extend Rogoff's model by integrating the Stages of Concern from Fuller's work in pre- and in-service teacher professional maturity [38]. As introduced with the travelers parable, the stages of concern follow individual progression through self-, task-, and outcome-oriented concerns as a model for maturing PI [38]. The resulting hybrid model, MPoC, supports research into PI as a situated construct, alternatively a Situated Identity research method.

My studies offer support for prevalence of emotional engagement in CS education and the CS capstone experience (RQ1), the structural influence of the capstone use of student preferences as engaging their interests and relevance, building toward confidence (RQ2), and exploring the dual model of developmental planes and stages of concern. Together, these studies portray ways that the CS capstone course influences CS PI formation. To further investigate and model these influences, my third research question is:

RQ3: What is the interplay between planes of development and stages of con-

cern as underpinning professional identity formation?

RQ3 builds on prior theories of learning and professional development, namely Rogoff's Multiple Planes of Development [78] and Fuller's Stages of Concern [38]. Rogoff's model focuses on development as evidenced by changing practices across personal, interpersonal, and community planes [78, 79], and CS capstone places students into collaborative teams engaging with the professional practices of software engineering. Fuller's model offers structure to identity formation as expressed through concerns, progressing across stages of self, task, and outcomes [38]. I propose an integration of the two models, suggesting a new model for development of confidence and concerns accompanying PI formation through changing practices. To explore RQ3, data draws from individual and team artifacts from the 2016-17 academic year, weaving together a case study across multiple teams of adopted practices with developing confidence and concerns.

1.2.5   Summary of Research Questions

My research questions and their associated data sources are summarized in table 1.1. Briefly, RQ1 establishes the role and validity of a focus on emotions, including confidence and concerns, as influencing student experience in the CS capstone course. RQ2 links interest-based course structures with student perceptions of relevance and real-world impact, which suggest connections of the course structure to outcome-oriented development of students. RQ3 directly examines evidence from individual and team artifacts in support of the larger model of Multiple Planes of Concern (MPoC).

1.3   Approach

I investigate the CS capstone course and its influence on CS PI formation through the theoretical lenses of situated learning and stages of concern. For this research program, I worked with one CS capstone course over five years, representing five distinct cohorts of students.

In the first three years (Academic Year (AY) 2013-14 through 2015-16), I worked as a teaching assistant and team mentor. The next two years (AY 2016-17 through 2017-18), I was the instructor

of record for the CS capstone course. This dissertation research draws on qualitative data from participants in the CS capstone, including interviews, individual, and team artifacts.

1.3.1 Research Context

The CS capstone in software engineering is a two-semester course series for students with senior standing in a CS major. Participants work in collaborative teams of four to six students with an external project sponsor from industry or the academic community. Sponsors bring a real-world need that they expect can be addressed through software, and agree to engage with a student team in support of exploring possible technical solutions.

Student teams have latitude in deciding how to structure their software development practices, and work to manage sponsor expectations as a significant part of carrying out the project. Teams operate in a supported environment, meeting weekly with a course teaching assistant in the role of team advisor. As needed, student teams consult with faculty across the university. Figure 1.1 presents the general timeline of the course, with assignments, evaluations, and rough milestones occurring during each academic year.

1.3.2 Data Sources

At a high level, there are two distinct segments of the dataset, namely interview data and course artifacts. A common thread across the dataset is the focus on student reflections. The

Table 1.1: Research Questions mapped to data considered.

RQ ID	Research Question	Data Considered
RQ1	What role does emotion play in influencing engagement and professional identity formation in a CS capstone course?	End-of-project Interviews, 2014-15 and 2015-16 AYs
RQ2	How does using student interest as the primary basis for forming teams influence student experience in their capstone project?	Early-in-project and End-of-project Interviews, 2014-15 and 2015-16 AYs
RQ3	What is the interplay between planes of development and stages of concern as underpinning professional identity formation?	Individual and Team Artifacts, 2016-17 AY
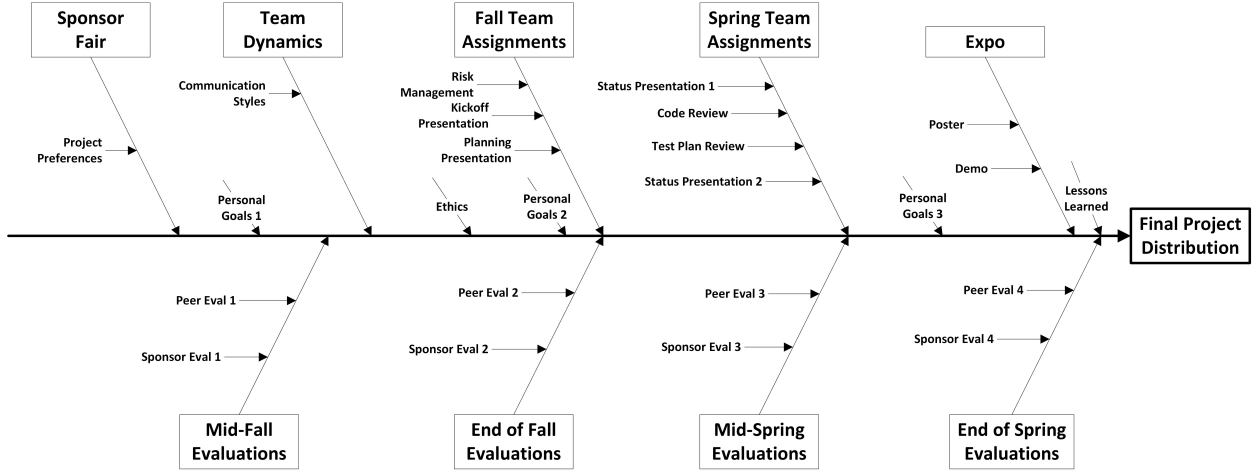
Figure 1.1: General course timeline for an academic year of the CS Capstone as implemented under this set of studies.

process of identity formation primarily occurs subconsciously, through "simultaneous reflection and observation" [31]. Reflective practices play a significant role in effective learning models [51]. My research approach gathers reflections by students in the CS capstone course about their experiences, both individually and discussed in their teams.

The first segment of the dataset is the interview data. In years two and three of the research study, students self-selected for interviews about their perceptions of project successes and failures, resulting in 26 interviews of about an hour each and about 300 pages of transcriptions. I personally conducted all interviews, which offers consistency in the approach of exploring what participants found to be meaningful about their project experience. The subsequent analysis leveraged undergraduate research assistants and readers from my advisor's research group. Early findings influenced assignments and activities for later iterations of the CS capstone course, such as adding the "Lessons Learned" team reflection assignment at the conclusion of each academic year. Interview participant information appears in table 1.2.

The second segment of the dataset is the individual and team artifacts. These class assignments capture open-ended responses to prompts about project expectations and evaluations. Figure 1.1 presents the general timeline of the course, with artifacts produced during the five academic

years involved in this work. Specific dates for each academic year are included in Appendix E.

Table 1.2: Interview participant demographics, drawing from 2014-15 and 2015-16 academic years and resulting in a total of 303 pages of transcription data.

	Participant Pseudonym	Gender	International Student	Comm. Style	Sponsor Type	Project ID	Indiv. Artifact Consent Granted	Team Artifact Consent Granted	Transcript Pages
AY 2014-15	Sofia	Female		Analytical	Industry	2-07	Yes	Yes	8
	Maria	Female		Amiable	Industry	2-11	Yes	**No**	9
	Noah	Male		Analytical	Industry	2-11	Yes	**No**	9
	Eric	Male		Analytical	Academic	2-03	Yes	**No**	12
	Owen	Male	Yes	Amiable	Industry	2-10	Yes	**No**	7
	Peter	Male		Analytical	Industry	2-06	Yes	**No**	5
	Thomas	Male		Analytical	Industry	2-10	Yes	**No**	10
	George	Male		Amiable	Industry	2-06	Yes	**No**	6
	Fred	Male	Yes	Amiable	Industry	2-07	Yes	Yes	9
	Elizabeth	Female		Expressive	Industry	2-07	Yes	Yes	10
	Ava	Female	Yes	Expressive	Industry	2-06	Yes	**No**	7
AY 2015-16	Jackson	Male		*not submitted*	Industry	3-01	Yes	Yes	13 + 0
	Lucas	Male		Expressive	Industry	3-02	Yes	**No**	16 + 19
	Zoe	Female			Academic	3-03	**No**	**No**	16 + 16
	Robert	Male		Analytical	Industry	3-08	Yes	**No**	8 + 8
	Diego	Male		Expressive	Industry	3-01	Yes	Yes	16 + 17
	Samuel	Male		Expressive	Academic	3-05	Yes	Yes	15 + 10
	Ben	Male	Yes	Analytical	Industry	3-08	Yes	**No**	10 + 17
	Michael	Male		Analytical	Academic	3-06	Yes	**No**	14 + 16

At a high level, these data sources represent student perceptions about their experience with the CS capstone course, whereby they join in interpreting what is meaningful about the course while bringing the (potentially) subconscious processes of PI formation to a conscious level.

1.3.3   Full Dataset Descriptions

The process of gathering the dataset for this dissertation research evolved over multiple years. The two major components of the dataset are interviews and course artifacts.

1.3.3.1   Interview Dataset

The initial work centered around one-on-one interviews exploring student perceptions of their CS capstone experience. The semi-structured qualitative interview instrument for conducting these interviews appears in Appendix A. Each interview lasted about one hour in duration, and participants were compensated with a $5 gift card to Amazon.com or Starbucks.

Eleven interviews were conducted in Summer 2015 with the 2014-15 cohort. As transcription and data analysis moved forward, I noted that student reflections may not provide a clear indication of *change* as a result of participation in the CS capstone experience.

To address this concern, a second round of interview participants were gathered from the 2015-16 academic year cohort of students. For these participants, interviews were conducted first during the Fall 2015 semester, referred to as *early project* interviews. Follow-up interviews were conducted in the final month of the academic year (May 2016) and into Summer 2016. Of the eight original interviewees, seven completed the *end of project* interviews (87.5% retention).

Demographics for interview participants appears in table 1.2. Participant names have been replaced by pseudonyms for ease of reference in publications.

1.3.3.2   Course Artifacts

Byproducts of participation in the CS capstone experience are individual and team classwork. These individual and team assignments are gathered for grading purposes, and retained in the CS

department's learning management system archive for ABET accreditation purposes. Many of the assignments include opportunities for introspective reflection, and as such offer potential depth of insight to supplement my research work.

A requirement for including academic artifacts in research work is gathering informed consent from the potential participants. Appendix B includes the consent survey whereby current and former students of the CS capstone course could indicate full or restricted consent for use of their academic artifacts in this research work.

Table 1.3 shows the total counts of individual artifacts where consent was granted for inclusion in research work for this set of studies. Individual artifacts include:

(1) Project preference survey

(2) Personal goals assignments (three total)

(3) Communication style assessment (part of team dynamics module)

Table 1.3: Individual artifacts with consent granted. Dashes (-) indicate no data.

Artifact	Academic Year					Total
	2013-14	2014-15	2015-16	2016-17	2017-18	
Enrollment	67	72	68	88	100	395
Consent Survey	44 (67%)	47 (65%)	53 (78%)	65 (74%)	96 (96%)	305 (77%)
- Career Influence	27	28	28	35	22	140
- Do not consent	1	1	-	1	-	3
Preference Survey						
- Top Five Projects	42	45	52	65	96	300
- Motivation	-	-	-	65	96	161
Communication Style	-	42	50	61	94	247
Personal Goals 1	41	45	50	63	90	289
Personal Goals 2	42	42	51	64	80	279
Personal Goals 3	40	42	40	50	75	247
Interviews						
- Early in Project	-	-	8	-	-	8
- End of Project	-	11	7	-	1	19

(4) Ethics case studies and reflections

Three potential participants responded to ask that none of their individual artifacts be used for research (0.8% refusal rate). 305 participants consented to use of their individual work for research (77% consent rate).

Beginning in the 2016-17 AY, the project preference survey was augmented to allow students to provide text describing their motivation behind their project preferences. From the instructor perspective of forming teams, it can be helpful to consider why students selected their preferred projects as a step in refining the project assignments. With consent to pull project preferences into this research work, the motivation text may be helpful in discerning factors considered by students. From 300 project preference submissions, 161 include project motivation data (53.7%).

In support of students developing greater capacity for healthy team interactions, course instruction includes a series of lectures on team dynamics. Beginning with the 2014-15 academic year, the module invited students to complete a communication styles assessment [57]. The results fed directly into class discussions about different strengths and weaknesses of the various communication styles, with the goal of introducing and modeling strategies for improved team dynamics. Of the 305 consenting participants, 247 had participated in the communication styles assessment (81%). This information may suggest insights into how individual students approach their team interactions.

As team artifacts represent the work of four to six students, the consent process required that all team members respond and provide their consent for the team artifacts to be used for research. The resulting dataset items of consenting teams and the grouped individual artifacts are presented in table 1.4.

Team artifacts include the following:

Table 1.4: Team artifacts where full team granted consent. Blanks indicate no data.

AY	Team	Proj Type	Team Size	Pref Mot	Pers Goal 1	Early Interv	Comm Style	Pers Goal 2	Pers Goal 3	Lessons Learned	Spons Eval	After Interv	Career Infl
2013-14	1-08	Industry	5		5			5	5	1	2		3
	1-12	Industry	5		5			5	5		2		2
	1-14	Industry	5		5			5	5	1	1		5
2014-15	2-07	Industry	6		6		6	6	6		4	3	4
	2-12	Industry	6		6		6	6	6		3		4
2015-16	3-01	Industry	6		6	2	5	6	6		4	1	4
	3-05	Academic	6		6	1	6	6	6		4	1	3
2016-17	Gamma	Industry	6	6	6		6	6	6	1	4		4
	Alpha	Academic	5	5	5		5	5	5	1	4		5
	4-10	Industry	6	6	6		6	6	6	1	4		
	4-12	Academic	5	5	5		5	5	5	1	4		
	Beta	Industry	5	5	5		5	5	5	1	4		3
2017-18	5-01	Academic	5	5	5		5	5	5	1	4		3
	5-02	Academic	5	5	5		4	5	5	1	4		
	5-03	Academic	6	6	6		6	5	5	1	4		
	5-04	Academic	5	5	5		5	5	5	1	4		3
	5-05	Academic	5	5	5		5	5	5	1	4		1
	5-06	Academic	5	5	5		5	5	5	1	3		1
	5-08	Industry	6	6	6		6	6	6	1	4		2
	5-09	Industry	6	6	6		6	6	6	1	4		
	5-10	Industry	6	6	6		5	6	6	1	4		1
	5-11	Industry	5	5	5		5	5	4	1	4		
	5-12	Industry	5	5	5		5	5	5	1	4		3
	5-14	Industry	5	5	5		5	5	5	1	4		2
	5-17	Industry	6	5	5		6	5	5	1	4		1
	5-19	Industry	6	6	5		6	5	5	1	4	1	2
Totals	26	Ind: 17 Acad: 9	142	102	140	3	124	139	138	21	95	6	56

(1) Project presentations

(2) Project test plan

(3) Project deployment plan

(4) Lessons Learned

(5) Project review minutes

Entries in the table for grouped team artifacts indicate the number of submissions included, collated by consenting team. This data represents the potential set of artifacts that can be grouped for investigating the team experience across an academic year. This type of within-group exploration underpins the case studies of chapter 4 and its accompanying manuscript [70].

Of 72 candidate teams from the five academic years under study, 26 fully consented to having their individual and group artifacts included for research purposes (36.1%). In-person recruiting as used for the 2017-18 AY was the most effective approach, as it resulted in 14 of the 18 teams granting full consent (77.8%). The case study work of chapter 4 focused on three of the teams from the 2016-17 AY, as the analysis occurred prior to the conclusion of the 2017-18 academic year, and in-person recruiting includes a constraint of not accessing any academic records until after final grades have posted.

1.4   Anticipated Contributions

Anticipated contributions of my dissertation research are summarized here, and discussed in greater depth in chapter 5.

1.4.1   Contribution 1: Theoretical Framework

In order to explore formation of PI in a CS capstone, I propose a novel theoretical framework, Multiple Planes of Concern (MPoC). MPoC builds on Rogoff's Multiple Planes of Development [78] and Fuller's Teacher Concerns Model [38]. The result offers a method for studying PI formation in

a situated context. Development of the framework and a case study applying it to artifacts from the CS capstone course comprise chapter 4.

1.4.2   Contribution 2: Recommendations for CS Capstone

My direct contributions from investigating the implementation of a CS capstone are specific recommendations for subsequent iterations of the course. These recommendations include both retaining current class features, as well as potential alterations moving forward. These recommendations may be of benefit to planning other capstone courses.

1.4.3   Contribution 3: Recommendations for Broader CS Discipline

Broader implications of this work offer recommendations for supporting PI formation across the CS discipline. This includes insights about CS coursework earlier than the capstone, as well as suggestions for post-graduation support.

1.4.4   Contribution 4: CS Capstone Dataset

The dataset comprising the combined data sources listed in tables 1.2 and 1.4 represents its own contribution. The generated dataset contains a collection of rich student interview data, class artifacts from individuals and teams, and survey responses including reflections on CS capstone influence after graduation. This CS Capstone Dataset is available to the public at [67].

1.4.5   Contribution 5: Class Artifact Consent Methods

To integrate course artifacts from student work, from both individuals and teams, I developed an informed consent process. This included two forms of outreach, namely in-person and through social media. My development of the in-person protocol is structured to gather informed consent while the course is in progress, though course artifacts will not be available until after grades post. This approach supports integrating informed consent as part of the course structure, lowering barriers to gathering full team consent. The policy directly benefits continued expansion of the

CS Capstone Dataset, by allowing in-person recruiting of subsequent cohorts while they are still engaged in their project efforts.

1.5   Reading Guide

Research questions are introduced in section 1.2.5. Briefly, the core research question unifying this dissertation research is, **what is the influence of a CS capstone course on undergraduate development of professional identity during the university-to-work transition?** My research explores this central question through the sub-questions in table 1.5, each aligning with a paper and presented in a chapter of this document. Chapter 5 weaves together findings from across each research question, offering insights around intellectual merit, broader impacts, limitations, and suggestions for future work.

Table 1.5: Research Questions aligned with papers presented in chapters of this dissertation.

RQ1	What role does emotion play in influencing engagement and professional identity formation in a CS capstone course?	Chapter 2	Reference [66]
Summary	The role of emotions through analysis of affective expressions in the interview transcriptions. Students reflected on the influence of the sponsor during project selection and later during evaluation. This may offer insight into the sponsor as a professional role model. Through recollections across the project experience, students expressed a range of valence (positive, neutral, and negative). Coding also explored the range of confidence and concern, showing preliminary usefulness of a confidence/concern spectrum during PI formation. This preliminary coding contributed to the development of Multiple Planes of Concern in chapter 4.		
RQ2	How does using student interest as the primary basis for forming teams influence student experience in their capstone project?	Chapter 3	Reference [68]
Summary	Focusing on the influence from the course structure of interest-based teams. Students referred to limits of previous academic project work and the legitimacy of the longer capstone experience in preparing for future roles in computing. With shared interest, students described their sense of engagement with the project and with their peers. The capstone differs from an internship in that students make and defend decisions about project processes, contributing to a sense of ownership over the project.		
RQ3	What is the interplay between planes of development and stages of concern as underpinning professional identity formation?	Chapter 4	Reference [70]
Summary	The process of conducting interview analysis contributed toward development of the Multiple Planes of Concern analytical framework. The focus teams for this case study draw from course artifacts, and explore both individual and team development of concerns. The analytical framework represents a novel extension of theory by combining Rogoff's Multiple Planes of Development [78] with Fuller's Teacher Concerns Model [38].		

Chapter 2

How Do You Feel: Affective Expressions from Computer Science Senior Capstone Projects

The following chapter is adapted from a paper presented April 22, 2017 at Learning and Teaching in Computing and Engineering (LaTiCE) in Hong Kong [66].

2.1   Abstract

Affective (emotional) responses contribute to student engagement and, ultimately, to the decision to persist or withdraw from Computer Science as a discipline of study. I investigate affective response as a factor contributing to engagement and professional identity formation during the university-to-work transition, as supported during a senior capstone project experience. By conducting qualitative interviews and focusing on student discussion of their emotional responses during the capstone project, I note three specific ways in which affective responses contribute to the student experience. First, students are receptive to the affective responses of project sponsors during project pitching and later evaluation. Second, student affective responses are present throughout the capstone project experience, and vary widely over the life of the project. Third, student affective responses provide an indication of their engagement and investment in the projects, and are linked to real-world impact of project outcomes. This paper presents a theoretical background for focusing on affective responses in the educational space, as contributing to engagement and professional identity formation. I conclude with suggestions for how these findings might inform educational development across the CS discipline.

2.2   Introduction

> There were certain parts of the technology that made me **nervous** ... that I've never done before. I was **very ambivalent** about the project, and **feeling like maybe I shouldn't have done this** *[Lucas, 2015-16, emphasis added]*.

A student made this statement at the completion of his senior capstone project experience, when asked to recall his feelings about the project as it was starting out. The student recalled emotions of nervousness and doubts related to the technology challenges of the project. Bloom proposed the Taxonomy of Educational Objectives, spanning the cognitive (thinking), affective (feeling), and psychomotor (doing) domains [3]. Each taxonomical domain offers a different focus for educational objectives, yet the importance of the affective domain is not prioritized consistently in computing education.

Research into interest and engagement has focused on the interplay between both affective and cognitive systems [46]. In particular, "the affective component of interest describes ... emotions accompanying engagement, whereas the cognitive component refers to perceptual and representational activities related to engagement" [46]. Recent results in computing education indicated that "computing best practices, and the value that these hold for students, are both cognitive and affective in their structure" [34]. In the introductory quote above, the student recalled specific affective responses including nervousness, ambivalence, and doubt or possibly regret about the project decision he had made. This is one of many examples I have collected from students during semi-structured qualitative interviews about their awareness of their affective responses with respect to their experiences in the Computer Science (CS) senior capstone course at our institution.

By downplaying the affective system in CS education as a community, we increase the potential for alienating students who *feel* as strongly as (or stronger than) they *think*. A seminal study into retention issues in CS focused on a concept referred to as the "nexus of confidence and interest" [55]. The authors used the term "nexus" to indicate that the factors of confidence and interest were related in impacting the decision to withdraw from CS, but did not differentiate the interplay between the two factors [55]. Another CS retention study concluded by posing the question, "is

there energy within the [CS] departments to make room for people who want strong bonds with people?" [9]. My central research question captured in this paper is: **RQ1: What role does emotion play in influencing engagement and professional identity formation in a CS capstone course?**

I first discuss the theories that underpin this research, culminating in specific research questions addressed in this paper. I then offer an overview of the CS capstone course as the context of my research. Next is the data collection process, followed by data analysis and results. A summary of the study outcomes and directions for future work concludes the paper.

2.3   Theory and Research Questions

The social concept of identity forms simultaneously through processes in the individual and in their social relation to the community around them [31]. In considering all learning as situated in a social context, Lave and Wenger examined the legitimate practices of apprentices as moving the individuals along a trajectory of participation with respect to the larger community of practice [53]. Wenger continued to develop his understanding of the interplay of participation with the communities around us, by considering how the practices an individual engages in relate to the various communities to which the individual might claim membership [95]. The concept of trajectory with respect to a community broadens to consider the set of trajectories a given individual experiences across their nexus of multimembership with multiple communities [95]. According to Wenger, identity emerges as the individual navigates tensions in how they perceive the differing values and behaviors accepted by the multiple communities of practice [95]. While Wenger focuses primarily on an individual experiencing multiple trajectories, the concept applies to individuals transitioning from one community of practice to another, as occurs with students moving into a profession.

While identity encapsulates all facets of an individual's way of thinking about themselves, I find it informative to consider specific social communities around which I can discuss specifics of identity alignment. I focus on the social communities of academic and professional identity for computing. The academic identity is alignment of a student with their identity as a student in a CS

or IT field of study [48]. The professional identity is alignment of an individual with their identity as a practicing member of a computing profession, such as software engineer [48]. Of particular interest are tensions emerging as individuals navigate the transition from the academic community of practice (university) to the professional community of practice (work place). Engagement is an expression of identity [75].

To ease the transition from university to work, programs such as internships, capstone projects [89], "year in industry" [29], and work-integrated learning [92] experiences provide opportunity for individuals to engage in practices considered legitimate by their professional community of practice, while still working to completion of the academic degree. The resulting space provides a bridge experience that may serve the role of a *turning point* [29] with respect to the individual's trajectory of participation. Fig. 2.1 depicts the transition students are expected to navigate, with panel A showing the transition without a bridging experience, and panel B showing the transition
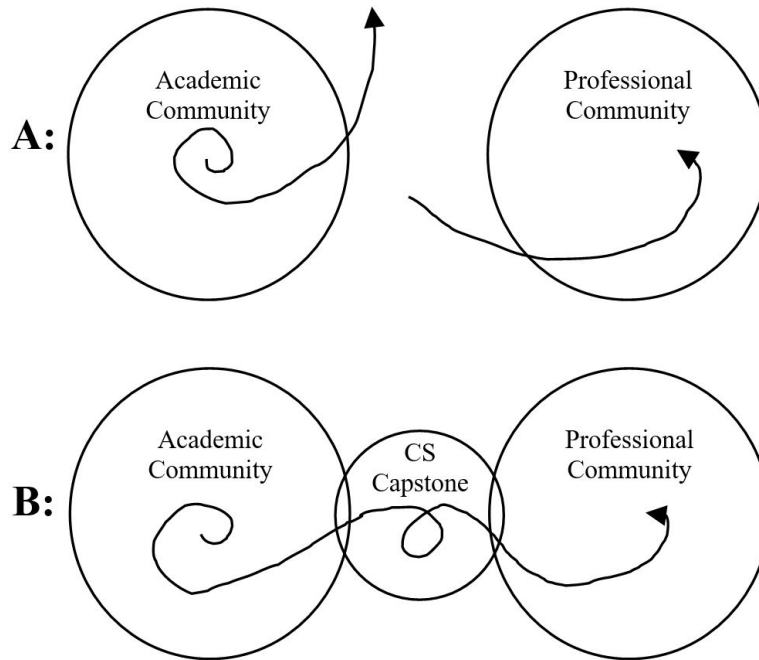
Figure 2.1: Without capstone experience (A), individuals try to transition out of the academic community while simultaneously transitioning into the professional community. With the CS capstone experience (B) positioned as a bridging experience between the academic and professional communities of practice, and connecting the trajectories of participation for an individual.

through a transitional program such as a CS capstone. The turning point experience changes the trajectory of participation in the academic community by helping the student to withdraw. At the same time, the turning point experience introduces the student into a trajectory of legitimate participation in the professional community.

The methodology employed in investigating identity continues to be qualitative interviews [75, 89, 29]. Much of identity formation occurs at a subconscious level [31]. Qualitative interviews provide participants with an opportunity for reflection and metacognition about their identity and factors influencing its formation or change. I am particularly interested in student perceptions of the space created by CS capstone courses. To understand their perspective of how the CS capstone course supports their development of professional identity, I have conducted preliminary work interviewing seniors who are completing their capstone experience [65]. This paper captures continuing analysis into and results from the interview data.

For the current study, I have focused on affective responses expressed by the study participants about their experience in the CS capstone course at my institution. The overall research question of this study is, "What roles do affective responses play in influencing engagement in CS students during their capstone experience?" Specific research questions addressed are as follows:

RQ1.1 How does emotional connection influence students during the project selection and evaluation phases of their CS capstone experience?

RQ1.2 How do student perceptions of their affective responses vary over the course of their CS capstone experience?

RQ1.3 How does student emotional investment relate to impact of their CS capstone outcomes?

2.4   Research Context

My university has offered its CS capstone option since the first graduating class of its Bachelors degree program in the 1987-88 academic year, and every year since then. Each iteration of the course runs for a full academic year, with project concepts drawn from industry partners and the

broader academic community. Students review the project options during the first week of classes in the academic term, meet with potential sponsors during a sponsor fair during the second week, and provide their top five project preferences to the instructors. The course instructors use the ranked list of preferences to form teams of four to six students, and announce team assignments in the third week of the academic year. Student teams then arrange for regular (usually weekly or bi-weekly) meetings with the sponsor organization, decide on their project management life cycle model, and select leadership roles for each member of the team. The teaching assistants (TAs, also referred to as Team Advisers) for the course meet with each student team weekly to mentor the team in professionalism, risk management, and to advise on any other aspects of carrying out the project.

In consultation with the project sponsor, the teams generally opt for an Agile methodology with sprint cycles of two to four week durations. Teams hone their technical communication skills through class presentations to their peers and instructors. As the academic year ends, the CS department hosts a CS Senior Exposition as a poster and demo session for the teams to display their project solution, and to engage in technical discussions about their experience with an audience of varied backgrounds.

In the space of the CS capstone course, students are engaging in authentic software engineering practices, working through all phases from requirements engineering through testing and deployment. The project sponsor guides the students in understanding the problem space for the project, lending legitimacy to the work performed by genuinely anticipating moving forward with the solution developed by the student team.

2.5   Data Collection

To understand student perceptions of the CS capstone course as supporting professional identity formation, I collected empirical data through semi-structured qualitative interviews.

2.5.1   Instrument

To gather reflections on their experience in the capstone course, a semi-structured qualitative interview invited open-ended dialog about project selection, external evaluation, and self-evaluation from study participants. I designed the interview instrument to examine student perceptions of project successes and failures. Students answered questions about their motivations for selecting their project, their perceptions of external sources of project evaluation, and their self-evaluation of the project experience.

Of relevance to this discussion about affective responses, the self-evaluation questions start with, "How did you feel about your project as it was starting out?", "How did your feelings change as the project moved forward?", and "How do you feel about the project now?". See Appendix A for the full semi-structured qualitative interview instrument. By explicitly phrasing the questions around the word *feel*, I expected participant reflection to offer affective responses.

By design, the semi-structured interview instrument supports consistency in posing these questions to all participants, while allowing open-ended responses and permitting the interviewer to probe for clarification or for additional details related to the response received.

2.5.2   Collection Procedure

Study population was the CS capstone course offering in the 2014-15 AY and the 2015-16 AY, for which the principal investigator worked as a teaching assistant. The study population for the 2014-15 AY was 72 students (18% female) and for the 2015-16 AY was 68 students (15% female). I conducted one-on-one interviews after final grades were posted, as approved by the Institutional Review Board (IRB) for human subject research. Study participants volunteered by responding to a recruiting email that outlined the study and offered a token monetary compensation ($5 gift card). For consistency in administering the qualitative survey, the principal investigator conducted all interviews in on-campus meeting rooms that were familiar to the participants. Participants consented to audio recording and transcribing of the interview. Once transcribed, I deleted the

original recordings. During transcription, references to individuals or organizations by name were replaced with role (i.e., "the instructor" or "the sponsor"). Each interview ran about 1 hour in duration.

Breakdown of study participants appears in table 2.1. The 19 students (26% female) volunteered to participate in the study, representing 13 of the 28 teams across the two academic years.

2.6   Data Analysis

Qualitative data present their own challenges for analysis. I relied on thematic analysis methods described in [11] and applied in [48] to review interview transcriptions and identify candidate

Table 2.1: Demographics of study participants, indicating mapping of academic year (AY), assigned participant pseudonym, and gender. Students represented a variety of projects.

	Participant Pseudonym	Gender
AY 2014-15	Sofia	Female
	Maria	Female
	Noah	Male
	Eric	Male
	Owen	Male
	Peter	Male
	Thomas	Male
	George	Female
	Fred	Male
	Elizabeth	Female
	Ava	Male
AY 2015-16	Jackson	Male
	Lucas	Male
	Zoe	Female
	Robert	Male
	Diego	Male
	Samuel	Male
	Ben	Male
	Michael	Male

themes for coding. [89] similarly described working with qualitative data by reading and rereading transcriptions to note what aspects of the data stand out as offering worthwhile insights into the phenomenon under study. Immersion in the rich interview data brought focus for this phase of the study to affective responses and the role they play in shaping the student experience.

2.7 Methods

During the reading and rereading by my research group, we noted that the data set includes rich descriptions of affective responses. The questions that invite direct reflection on feelings and how they change over the project were a major source of these affective expressions. In addition, participants offered emotional insights across other sections of the interview, including project selection and the self-evaluation of the project experience.

To focus explicitly on affective reflections present in the transcripts, I identified phrases as data extracts that potentially offered insight into the student's affective expression. As reading emotion into transcribed text entails subjective judgment, the research group then categorized these data extracts with respect to valence with labels "positive, neutral, negative, or N/A". Seven researchers conducted the categorization step across 133 data extracts. By considering a label to be assigned to a data extract if six or more members of the research group assigned the same label, the categorization produced 68 data extracts categorized as positive valence, 10 as neutral valence, and 39 as negative valence.

In addition, I noted in processing the data extracts for valence that specific emotions appear as themes across the interviews. These included confidence, nervousness, frustration, and anger. To explore prevalence of specific emotions, I categorized the same set of data extracts with respect to confidence with labels "confidence, neutral, uncertainty, or N/A". As the task focused specifically on the single emotion of confidence, fewer data extracts were assigned labels. The categorization of confidence produced 22 data extracts categorized as confidence, 5 as neutral, and 11 as uncertainty.

The two categorizations serve to focus the analysis on sections of the interview transcripts where participants are exposing their affective responses. Specifically, I first group affective re-

sponses with respect to the role of the sponsor. Next, I consider the dual categorization of affective responses between valence and confidence. Finally, I group affective responses linked to the impact or outcomes of the project.

2.8   Results

2.8.1   Affective responses with respect to the sponsor

Once labeled, I examined data extracts containing affective responses, and found logical groupings of the extracts. This first group of data extracts show student awareness of emotions of the project sponsors.

Potential project sponsors met directly with students in an informal "job fair" setting, where students asked clarifying questions about the project proposals and practiced networking skills by distributing resumes. In addition to clarifying the scope and expectations for projects, students used the face-to-face interaction as an opportunity to read into the sponsor's emotional connection to the project. Study participants included comments such as the following in describing what attracted them to some projects:

> Definitely the people [sponsors]. How they presented themselves. If they seemed like they would be **fun** to work with or a good customer, or how into it.... Once I met the people, I feel like they were better at selling me on wanting to be a part of the project *[Maria, 2014-15, emphasis added]*.

The student recalled specific emotional connections rooted in meeting in person with potential sponsors. The next extract focused more specifically on reading the sponsors' level of excitement and energy with respect to the pitched project:

> What attracted me really was the way it was presented by the sponsor at the sponsor fair, at the project fair, kind of the vibe I got.... Once I got to the [sponsor] fair, **feeling the vibe** from each of the sponsors, and if they were **excited about it**, how they spoke about it, and the extra detail they gave me about the project really drove me to narrow it down further *[Thomas, 2014-15, emphasis added]*.

In addition to positive emotions such as excitement, students also recalled affective responses of the sponsors with other factors that drew them away from some projects:

> Actually, I remember one [project concept]. It just sounded **really boring**.... [The sponsor] presented it, in a **really uninteresting** way, and it seemed like it would be a lot of grunt work, not a lot of interesting programming, and a lot of redundant work *[Ava, 2014-15, emphasis added]*.

These interview responses raise interest because they depict student perceptions of affective responses of the project sponsors, and that students linked their perception to an assessment of how invested the sponsor might be in the project concept.

The interviews invited participants to consider external sources of project evaluation, and all responses included discussion of the role of the project sponsors in providing an evaluation on the team. Students recalled reading affective responses of the project sponsor in gauging how the project was received:

> [The sponsor's] face when he saw it. No, he was really good at giving **positive** feedback throughout the process. Any time we would send him videos or send him a status update like, 'Hey, check this out. We got this X to work,' he was **pretty emotionally invested** in the project. You could tell that he was **happy** with what we were doing. He would give us feedback, too.... He would say, 'You guys are doing great. Your documentation is looking good. I think you're on the right track,' etc. *[Diego, 2015-16, emphasis added]*.

This response includes focus on both the words offered to the team as feedback, and that the student recalled reading emotions on the sponsor's "face." As with the recollections of the sponsor fair, the student here noted the sponsor's emotional investment in the project.

2.8.2 Student affective responses of their project experience

After completing the labeling of affective data extracts based on valence and confidence, I next consider the interplay of the two categories. Results are presented in table 2.2. Coding of data extracts produced entries across all three labels of the valence category, and across all three labels of the confidence category. Combining the two categories in the table layout, the most prevalent

Table 2.2: Data extracts from interview transcriptions, grouped by category labels for valence (postive, neutral, and negative) and confidence (confidence, neutral, and uncertainty). Additional data extracts have been excluded from positive-confidence and negative-uncertainty for brevity in presenting this data. Total count of data extracts have been indicated for each sector in italics.

		Confidence		
		Confident	**Neutral**	**Uncertain**
Valence	**Positive**	**Count: 28** "kept getting more and more optimistic" - Eric "became more confident" - Noah "more and more optimistic" - Thomas "confidence" - Maria, Noah, Owen, Lucas, Robert, Samuel "I feel good about it" - Sofia, Jackson "best experience in college" - Noah "once started, it was easier to feel like I can do this" - Maria "I'm ready to go" - Diego "things are looking pretty good" - Ben	**Count: 1** "still excited about it in the long run" - Lucas	**Count: 1** "It's the anticipation of, 'this is going to be really cool' ... but it's also reality" - Lucas
	Neutral	**Count: 2** "not concerned" - Lucas, Diego	**Count: 4** "ambivalent" - Lucas "a lot more up and down" - Sofia "kept expectations in check" - Eric "bitter-sweet" - George	**Count: 2** "I didn't know what to expect" - Eric "tentative ... timid" - Maria
	Negative	**Count: 1** "We're wasting a lot of time" - Zoe	**Count: 6** "starting the project was a little bit tough" - Maria "jaded" - Eric "disappointed" - Maria, Peter, Elizabeth	**Count: 21** "maybe I shouldn't have done this" - Lucas "nervous" - Noah, Eric, Elizabeth, Lucas, Zoe "a little nerve racking" - Noah "a little bit intimidated" - Lucas "worried" - Eric, George, Elizabeth, Diego, Michael "underprepared" - Maria "apprehensive" - Eric, Thomas, Jackson "This is not going to happen" - Elizabeth, Lucas "overwhelmed at first" - Maria, Ben

responses are in "positive-confidence", followed by "negative-uncertainty", and then by "neutral-neutral". This is consistent with confidence as generally associated with positive emotions, and uncertainty generally associated with negative emotions.

By asking students to reflect on their feelings at the beginning of the project, as the project progressed, and at the conclusion of the project, the data extracts represent recollections of the emotional side of the experience at those snapshot points in time (fig. 2.2). By plotting a value representing the difference between number of positive affective responses and number of negative affective responses, I note that generally students relate a variety of emotional states over the course of the project. Connecting the snapshot points by lines offers opportunity to look for trends in emotions over time. While all participants who discussed their emotional assessment express variations in their affective state over the course of the project, there is no consistent trend. Responses as the project starts out vary from nervousness to excitement. Responses as the project progresses vary from increasing confidence to increasing frustration and doubt. After the
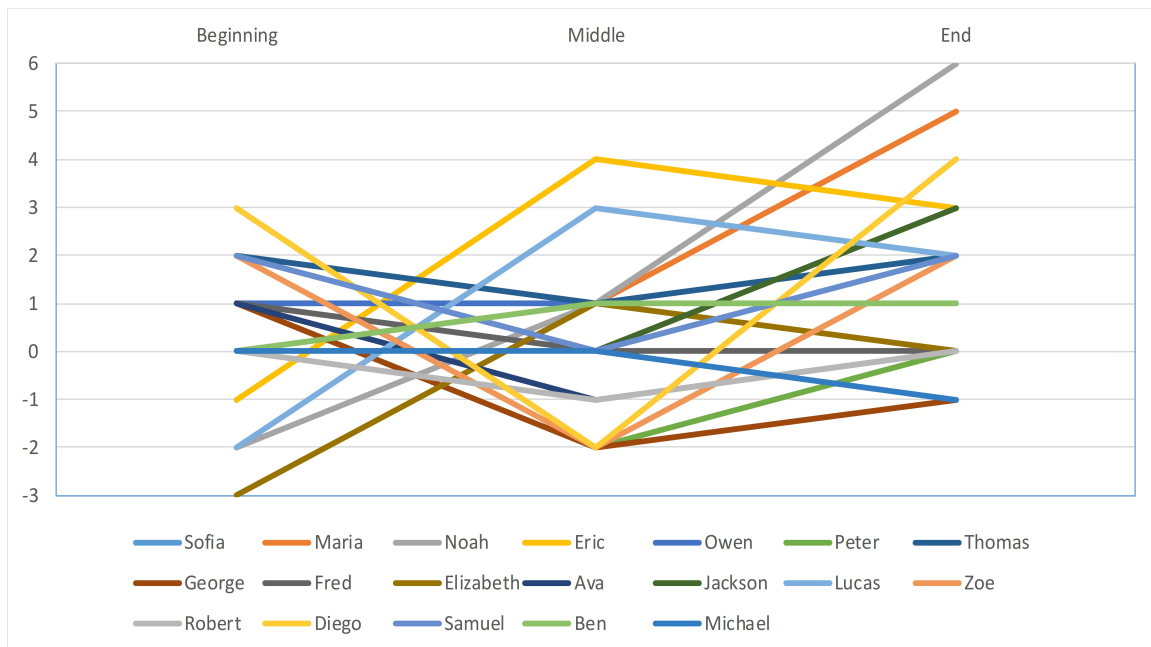
Figure 2.2: Trends of affective responses at beginning, middle, and end of project, as recalled by students after conclusion of capstone. Value at each stage represents total of positive valence terms, minus negative valence terms.

experience, responses vary from satisfaction to disappointment. The variance present in the data extracts speaks to the breadth of affective responses experienced by participants in the course. There is no one consistent set of affective states experienced over the life of the project. Rather, the experience entails highs and lows, from start to end.

The variety of affective responses is intriguing, as the participants express these diverse emotions across the project experience that lasted a full academic year. Participants recall these affective responses in relating the narrative of their experience, as well as in response to direct questions about their feelings during and about the project experience.

The semi-structured interviews set out to explore student perceptions of successes and failures as outcomes of their CS capstone experience. Fig. 2.2 depicts a spread of affective responses at all stages of the project, especially at the conclusion. All students indicated ways in which their projects were successful and unsuccessful. Some students felt that their project experience was *challenged*, in that they struggled to meet the project sponsor's expectations by the end of the academic year. Often the students on these challenged projects provided more instances of comments reflecting negative valence, perhaps expressing frustration at not having been more successful. Yet the students on these challenged projects still identified successful outcomes of the experience, and still focused on project impact. Often their responses included significant lessons learned that would be influential on future project work.

In a similar manner, students who were very pleased with the outcome of the project experience were still able to identify ways in which the project was unsuccessful. In most cases these unsuccessful outcomes related to software engineering "best practices" that the students valued more strongly after the capstone experience, but felt had not been adequately integrated and demonstrated in the project. As noted in [34], "Computing best practices, and the value that these hold for students, are both cognitive and affective in their structure". I feel that student affective expressions captured in this study support that statement.

2.8.3   Student affective responses linked to project outcomes

The labeling of affective responses brought focus on emotional connections between the student experience and the impact the project would have. Once I realized this link, I again reviewed the transcripts to target comments related to student perceptions of project impact. While I keyed into this group of data extracts by the affective response labeling, some of the final data extracts do not include emotionally charged phrases, but only an explanation by the study participant that the project impact was a consideration. One participant described the consideration of impact in this manner:

> I want to get a job, but I also want to get a lot out of my education. I didn't want it [the capstone project] to just be a means to an end *[Lucas, 2015-16]*.

Some of these passages occurred in response to the discussion about project selection, where participants recalled their perception of project impact as a factor under consideration:

> That was built on the content of the project. The project that I worked on, I got the idea that it was something that they wanted to do for their employees as something that would be fun to have as a competition *[Maria, 2014-15]*.

The participant of the next passage indicated that they came to the sponsor fair ready to pose questions to differentiate the projects. I asked for examples of questions posed, and was told:

> One of the things I remember was, 'Who is going to be using this product?' I was trying to see if that was a toy project they had, or an actual project they are going to use.... If it's something that they were actually planning to use, or they really have a need for it, then it would really be a personal satisfaction of saying that's actually the software we built being used by someone *[Owen, 2014-15]*.

As some students have completed internships during their academic studies, they are in a position to offer comparisons between work done toward an internship and work on a CS capstone project. This participant mentioned considering *impact* during project selection, and explained the term as follows:

> There's some internships that you have to do a lot of busywork.... I've been being able to work [on this CS capstone project] with something that actually impacts either 1, yourself, or 2, the company as a whole. Or 3, even, all of science. The more progressive [it] is, the higher impact, and the more involved you actually are with the company itself, is impact. Personal impact is definitely how good it's going to look on your resume *[Jackson, 2015-16]*.

These responses are samples of the importance of project impact raised during discussion of project selection. Participants also discussed project impact when considering their self-evaluation of the CS capstone experience.

> I hope that the sponsors, if they're not using it now, I hope that they have plans for it, to make it better, or maybe even get another senior project team involved to move it along from where we started, or from where we ended rather. To see if they could take it even further. That would be cool *[Noah, 2014-15]*.

The CS capstone project links students to projects with real-world impact. The responses from study participants indicate that many students are aware of this link. Students consider the potential for impact of the project during project selection and evaluation. This is consistent with individuals moving through their transition from the academic community to the professional community as they engage in computing practices during their capstone experience.

2.9   Limitations

Qualitative interviews provide opportunity for participants to reflect on and share their experiences through open-ended questions. The exploratory nature of this work offers insights into student perceptions of their experience in the CS capstone course, but does not speak to prevalence of identified themes nor exhaustive enumerations of factors. If a topic was not explored in each interview, this is not an indication that the topic would not have been applicable for a given participant.

Studies focusing on affective responses are challenging, given the subjective nature of categorizing emotional responses. Some participants did display avoidance of discussing feelings. For example, one participant responded with "I ***thought*** it was going to be a lot more challenging"

[Robert, 2015-16, emphasis added], while not divulging anything connecting to an affective expression.

Multiple factors influence the likelihood that interviews will include discussion of affective responses. In the discipline of CS, the prevalent personality type tends to be less expressive and more guarded about sharing emotions [16]. Cultural pressures may prevent men from verbalizing their emotions, and the study population is predominantly male. Both factors possibly are offset by the interviewer having worked with the course offerings in the role of a teaching assistant. Interviews were conducted after grades posted to ameliorate perceptions of possible bias in responding. Participants may have found it easier to relax and be more open about sharing their experiences and their affective responses because of the familiarity with the interviewer.

This study drew participants from the senior cohort of students across two academic years at a public research university in the United States. Demographics of the study population mirror enrollment at the institution.

The findings of this work contribute to my understanding of the role of affective responses in student engagement and professional identity formation during the university-to-work transition.

2.10   Discussion

Categorizing data extracts with respect to valence and confidence yielded a two-dimensional space (table 2.2). Plotting prevalence of statements with positive and negative valence produced fig. 2.2, depicting a spread of emotions at each stage, as well as changes from one stage of the project to the next. In [19], the author proposed that educators in computing consider their teaching as a *drama* production with students moving through an "emotional rollercoaster". By planning for the dramatic arc of the learning experience, educators can better facilitate learning in their classroom. The author noted, "education is an inherently challenging and confronting experience for the student" [19]. He went on to describe the emotional challenges inherent in significant learning experiences:

The dramatic journey ... with its highs and lows will be familiar to anyone who has engaged in real learning. This is especially true to ... any committed educator who has had to deal with students struggling through the trough of despond, wrestling with discomfort, and in quiet desperation crying in a teacher's office [19].

The interview data depicted in fig. 2.2 describes significant emotional "highs and lows" [19] encountered as students worked through the legitimate challenges of their capstone experience. As the CS capstone experience bridges the academic and professional communities of practice (depicted in fig. 2.1), students move along a trajectory of participation [95] while forming their professional identity. Consistent with [31] and [46], this professional identity formation process occurs across cognitive and affective domains. The semi-structured interviews I conducted in this study provide students a space for reflection on their experience, which can help individuals bring their identity formation experience into a conscious level of understanding.

By focusing on the affective expressions present in the interviews, I have identified three specific roles that the affective domain plays during the CS capstone experience. The three roles correspond to my three research questions.

Students invest themselves emotionally in their CS capstone projects. Their engagement begins with their face-to-face interactions with potential project sponsors, and the emotional engagement that the students perceive from the sponsors. Students recall positive energy from the sponsors that draw them in, and neutral or negative energy from the sponsors where they are repulsed. Students read their sponsor's affective expressions as the sponsor reacts to project updates and outcomes. Speaking to RQ1.1, students are aware of the affective expressions of the project sponsor, and this awareness influences the student emotional connection to and engagement in the capstone experience. I mirror the recommendation from [34], "Hence the need for educators to better model these types of affective domain learning outcomes, and be able to assess them reliably."

RQ1.2 focuses on student affective responses and their variation over the academic year in which they contribute to the project. This variety of emotions throughout the capstone experience speaks to the breadth and depth afforded students by their engagement in their projects. The short answer to RQ1.2 is that student perceptions of their affective responses vary widely over the

course of the experience. The same participants relate feelings of optimism alongside apprehension and nervousness. I believe these responses authentically represent the breadth and depth of student experiences.

While RQ1.1 focused on student perceptions of sponsor affective expressions, RQ1.3 keys into student expressions of their own affective experience as linked to discussion of project outcomes. Students are engaged and motivated by the potential for their software engineering contributions to have real-world impact through the capstone project. [96] surveyed student values motivating the project selection process. A value of particular interest was "social value" [96], although the authors struggled to link to "social good" or "social bad" as a value related to the project [96]. I believe that students feel an emotional connection to their project work, and that the project sponsor legitimately values the work done by the student team. Whether the final solution is ready for deployment or will inform the ultimate direction that the project moves forward, the sponsors are invested in the solution developed by the student team.

This finding is consistent with the shift of values away from the academic community and toward the professional community, as resulting from a turning point experience that alters the trajectory of participation (fig. 2.1) and accompanies formation of a professional identity. In the academic sphere, teachers pose class assignments with student learning as the most significant expected outcome. In many cases, any given student's developed solution is one of many instances implemented by the cohort of students in that course. Generally, all completed implementations are discarded after the evaluation phase. In contrast, capstone projects are conducted for real-world sponsors with a specific need to be satisfied. The team's effort is often the only implementation of a solution actively under development. As a result, students can easily see the impact of their work.

Legitimacy was a focus in [53] as a factor in guiding participants' trajectories from a peripheral role to one of central participation in a community of practice. Student perceptions are consistent with the capstone experience offering opportunity for legitimate engagement.

2.11   Conclusions and Future Work

The overarching research question of this study, RQ1, considers roles affective responses play in influencing engagement. The findings captured in this report indicate that students are perceptive of sponsor affective expressions during project pitching and evaluation; that students experience and express a diverse range of experienced affective responses over the course of their project experience; and that student engagement is linked emotionally to the real-world impact of the project outcomes.

Student perceptions are consistent with awareness of the capstone in serving as a bridge between the academic and professional communities of practice [95], and as a *turning point experience* changing their trajectories of participation [29] in relation to the two communities (academic and professional). Their role of participation during this transition is simultaneously one of withdrawing from the academic community of practice, and moving to a more central role of participation with the professional community of practice. As proposed by [46], the affective system complements the cognitive system, both contributing to individual interest and engagement.

Future directions for research will focus on student concerns related to their adoption of a professional identity. Improved awareness of student concerns by educators and mentors can support guiding them through the "emotional rollercoaster" of their academic studies and school-to-work transition [19]. While this study focused specifically on emotions as evidenced in the interview transcripts, I anticipate conducting additional targeted interviews with a focus on identifying concerns across the social interactions of the team environment, and the shift in practices and values accompanying the transition across communities of practice.

Findings from this study encourage educators in computing to model authentic affective expressions about the discipline, to prepare to support students as they work through the highs and lows of their experiences, and to link outcomes of computing tasks to real-world impacts, including emotional impacts.

Chapter 3

Interest-Based Capstone Team Formation

The following chapter is adapted from a paper, a poster presented June 4, 2018, and a panel presented June 6, 2018, at the Capstone Design Conference (CDC) in Rochester, New York [68].

3.1   Abstract

How might student teams be formed to prioritize individual engagement and motivation, given a cohort of students and a batch of capstone project concepts? For the capstone course in the Computer Science Bachelor's degree at University of Colorado, students rank their top five project preferences and instructors use that indication of interest as the driving factor in forming teams. Students in two years of the CS Senior Projects capstone self-selected to participate in a semi-structured qualitative interview about their experience. This paper investigates how use of student interests as the primary basis for forming capstone teams may influence students' perceptions of their experiences in the capstone project. Themes include legitimacy of real-world projects, engagement of students, and ownership of project decisions.

3.2   Introduction

> I really liked that it was a project that I was interested in.... I was like, 'I really
> care about this field! I'm really passionate about it!' And I know that some of my
> team members were really excited about the domain as well *[Elizabeth, 2014-15]*.

A challenge faced when implementing a project-based capstone course is determining how to organize a cohort of students into teams and, once organized, how to motivate the students to engage

in working on their projects. In short, how do we spark interest in supporting the project?

Processes for organizing capstone students into teams may consider different levels of input from students, from no input (perhaps random assignment), to minimal input (resumes or skills of interest), to maximal input (having students decide their own team members and notifying instructors of their decisions). Each of these options has trade-offs to be considered. For example, team assignment based on instructors matching student backgrounds and skills to project needs may provide a skill-balanced team, but may place students together who do not see the project as relevant to their interests and then struggle to engage. Allowing students to form their own teams may support students in expressing their interests, while potentially resulting in unbalanced teams that struggle to meet the project outcomes.

As the introductory quotation from a student interview conveys, students are aware of their interests and the interests of their teammates. This paper considers the question, **RQ2: How does using student interest as the primary basis for forming teams influence student experience in their capstone project?**

The Computer Science (CS) department at the University of Colorado (CU) has included a software engineering capstone course as part of the Bachelor's degree since the first senior cohort in the 1987-88 academic year. Since the 2012-13 academic year, this CS Senior Projects capstone has driven team formation primarily by student preferences. To explore the impact of this practice on student experience, I carried out qualitative interviews with capstone participants after the 2014-15 and 2015-16 academic years. During this study, I worked as a teaching assistant for the course. My hypothesis is that primarily interest-based team selection may support student motivation and engagement with their project and team.

Literature related to interest and its role in learning is presented. I review the interest-based team selection process in the context of the CS Senior Projects capstone course. Methods for conducting and analyzing qualitative interviews are briefly presented, followed by interest-related results of the thematic analysis. Discussion about results and possible implications conclude the paper.

3.3   Relevant Literature

My working definition of individual interest is "a relatively enduring predisposition to reengage particular contents over time", and "to problem solve and seek out answers to questions" [46]. Interest is "characterized by varying amounts of affect, knowledge, and value" [46]. Specific to CS, researchers investigating students who decide to withdraw from the CS major have found a "nexus of confidence and interest" [55], indicating that loss of confidence and loss of interest may accompany a decision to change majors. For purposes of this paper, the key conjecture is that interested students will tend to be more engaged, will make decisions to persist despite frustrations, and will exhibit greater confidence [46, 55]. When considering interests and engagement in capstone courses, confidence can augment technical skill development [76].

Interest and engagement in learning may be more readily motivated when students find the learning tasks personally meaningful and relevant [74], suggesting that if project assignment is driven by student interests, students may experience an easier path to engaging with their projects and persisting despite challenges and frustrations.

Based on the interest literature, an interest-based team selection process may support deeper engagement and successful experiences in the capstone course. A recent study noted that consideration of student interests during team assignments "aim[s] to give students an element of choice in the project they undertake" [96]. The authors stated that they take student preferences into account as one of several factors considered by a panel assigning teams, whereas the team assignment process at CU makes student interests the driving factor in team formation.

3.4   The Context

The implementation of the CS capstone course at CU is a software development project that runs for the full academic year. External sponsors propose project concepts, both from industry partners and members of the academic community. The course is directed by an instructor assisted by two teaching assistants as the teaching staff. Together, they mentor teams of four to six students

in the practices of software project management.

Sponsors submit a two-page project proposal prior to classes beginning, and attend a Sponsor Fair during the second week of class. The Sponsor Fair is modeled after a job or career fair, with each sponsor organization at a table to recruit for their project. Many sponsors bring technical material related to the project that may help with explaining the scope, such as a previous prototype or part of the system that would be supported by the project.

Students receive the written project proposals during the first week of the class. They prepare and submit their current resume prior to the Sponsor Fair event. At the Sponsor Fair, they practice networking by distributing copies of their resumes to potential project sponsors, and explore the various project options available to them.

3.4.1 Team Formation Process

After the Sponsor Fair, students submit their top five project choices, ranked in order of preference. The preference survey asks about leadership role preference (strongly prefer to lead to strongly prefer not to lead), intellectual property (IP) rights preference (strongly prefer to retain IP rights to no preference to retain IP rights), strength of a variety of technical skills (none, basic, good, proficient), areas of desired learning (open-ended list of skills), suggestions of who to work with, people who will not work well together, and GPA.

3.4.2 Team Formation Guidelines

Students are assigned to projects by the course instructor and teaching assistants. For the 2014-15 academic year, this involved assigning 72 students across 12 teams of 6 students each. For the 2015-16 academic year, there were 68 students across 12 teams of 5 and 6 students. For each year, the team formation process required about four hours of iterative discussion.

An inviolable consideration is people who will not work together well, as there may be prior bad experiences. The defining factor of team assignment is that iterations are driven by project preferences. The initial iteration of assignments is based on first preference choices, up to 6 students

for each team. For partial teams, second (then third, etc.) choices are considered until the team has at least 4 students. Subsequent iterations continue by considering removing students from a placed team so they become candidates for a lower preference project. The guiding rule is to move previously placed students from a higher preference to a lower preference to make room for a student who has not been assigned on one of their higher preferences. This introduces a maximizing function of placing students on their highest preference, while prioritizing placement of students whose preferences are more restrictive.

Teams are announced in the third week of the class. Each team selects their team lead and schedules their first sponsor meeting. From that point, teams refine project scope and requirements, identify risks and tasks, and run their project. Each team meets weekly with a member of the instructional staff.

3.5   Research Methods

To investigate the influence of the interest-based project selection on student experiences, students of the 2014-15 and 2015-16 academic years self-selected to participate in semi-structured qualitative interviews about their project's successes and failures. Questions focused on project selection ("What drew you to some projects? What drew you away from other projects?"), external evaluation ("Who evaluated your project? What information was available to them to consider?"), and self-evaluation ("In what ways was your project a success? In what ways was your project unsuccessful?"). These questions allowed students to offer open-ended reflections on their experience. Interviews were conducted by phone or in person, lasted about an hour, and were completed between 1 week and 2 months after the conclusion of the capstone course. Participants received a $5 gift card as a token compensation for their time. Of the 140 students (12% female) enrolled in the course over the two academic years, 19 students (26.3% female) self-selected to participate in interviews. Demographics such as race/ethnicity or first-year students were not collected.

Analysis of interview transcripts followed the methodology of thematic coding [11], with a research group consisting of the principle investigator and an undergraduate research assistant. To

explore themes, the transcripts were read and reread, with regular discussion of possible themes of interest, mainly around what participants expressed as meaningful about their experience. These themes were developed into a coding dictionary for consistent use across readers in applying the thematic codes. For purposes of this paper, I focus on the role of team interactions and engagement as themes identified in the thematic coding process.

3.6   Results

Thematic coding resulted in a variety of concepts related to personal meaning. Specific to the focus of this paper on the role of interest-based project selection are legitimacy of real-world projects, engagement of students, and ownership of project decisions. Here, each of these themes is described with selected extracts from interview transcripts to demonstrate what is captured by each.

3.6.1   Legitimacy of Real-world Projects

Multiple interview participants discussed differences between the capstone experience and previous coursework. Some described previous assignments as not equivalent to *teamwork* because of small group sizes (two to three students), short durations, and limited scope. By contrast, the capstone experience team sizes were more authentic to what students anticipated real-world teams to be. Longer project durations require working through team dynamics issues rather than just pushing through to a nearby deadline. In terms of project scope, one student thought about it in the following manner:

> It was a huge learning experience, building something that was so much larger than anything we had ever done before.... [Capstone] was the first experience that I had had with building something where my project team really had control over all the moving parts, and was tasked with creating each of those moving parts, and making them move together in a way that wouldn't blow up *[Eric, 2014-15]*.

Along with noting similarities with real-world software development practices, participants noted that the academic space has limitations to its legitimacy. Examples of key differences include

the challenge of managing varied schedules and non-project commitments. A benefit of these limitations was described as follows:

> It's really nice having it in this school format where if you make a catastrophic screw-up, the worst-case scenario is we get a B in the class..., instead of getting fired, which would actually be catastrophic, or at least emotionally catastrophic *[Samuel, 2015-16]*.

While actual impact to grades may be more severe, the academic space around capstone projects does offer a safety net as students work through challenges. In addition to the capstone instructional staff, the course relies heavily on the faculty and university staff to assist with overcoming project obstacles.

3.6.2   Engagement of Students

Several students noted that their team started into the assigned capstone project with excitement and motivation. Four of the nineteen interview participants were team leads. A team lead described his concerns with overseeing individual team members:

> On more of a personal level in terms of success, ... I was looking at, ... 'How can each of my teammates contribute and be productive?' So long as everyone was doing everything that they could and being as productive as possible, I didn't really care how far we got, how great the thing looked. I just wanted it to be a great effort *[Thomas, 2014-15]*.

Interviews included teams that encountered frustrations and struggled with lack of engagement and low morale on occasions. Despite the struggles, participants noted the value of their interest and engagement on project success:

> [I]f you're given the option to do something that you care about, you're going to feel better about it, and you're going to produce better work.... [T]he fact that I'm driven and passionate to learn, and that I want to pursue something great, I think that [on] a team, I'll be able to contribute great work to it. *[Diego, 2015-16]*

3.6.3   Ownership of Project Decisions

A key difference between capstone experiences and internships is that capstone students carry the responsibility to make project decisions. The following captures this concept of making and defending decisions with respect to the capstone project:

> My expectations of teams is a little bit colored by ... being able to delve into things and talk openly about design, and not have people get offended if you criticize the design decisions, and having your design decisions criticized as well, because that's all in building a good product *[Eric, 2014-15]*.

A strong example of team ownership of the project direction was described by Thomas:

> [H]aving gotten a month or two into [development], and really ... digging out the weaknesses of the software stack we chose, we all had a serious conversation about it. And at that point..., we're willing to go back on a month of work..., because we know ... this is going to help us get to our end goal *[Thomas, 2014-15]*.

3.7   Discussion and Conclusions

This paper describes a process for forming capstone project teams based primarily on ranked student preferences. Qualitative interview data offers evidence of student perceptions of their capstone experiences. For the CS Senior Projects capstone, students interact directly with potential project sponsors at the Sponsor Fair event prior to selecting their project preferences. In addition to the written two-page project pitch, the Sponsor Fair serves to acquaint students with individual sponsors. As such, their project preferences represent informed, not blind, interests. Students have an idea of how well versed the sponsor is in the project concept, how invested they are in its success, and how enthusiastically they speak about the idea. When students submit their project preferences, their initial curiosity about project concepts have matured into full interest and a desire to see the selected projects progress.

Interest-based team formation has its own trade-offs to be considered. In some settings, the time for iteration may be prohibitive. A risk is that the interest-based process may produce teams lacking specific skill sets. On the other hand, a team where all members share a common interest

in seeing the project succeed may support stronger collaboration, such that the team may be more successful in overcoming those shortcomings and other challenges such as interpersonal conflicts and team dynamics.

To investigate the influence of interest-based team formation on student experiences and learning, qualitative interviews gather self-reflections on the project outcomes. Relying on interviews with self-selected students results in limitations to this study, including that interviews may not be fully representative of all experiences in the course. Despite this, findings suggest strengths of the approach considered.

Students expressed concerns about balancing efforts across teams in an academic setting, yet most participants indicate that their capstone projects felt legitimately like real-world project work. This balance between academic and real-world settings is consistent with "fertile zones of cultural encounter" as creating an authentic professional project space that retains its educational focus [8]. Students reported feeling engaged with the project, and that their peers were engaged on their team. This is consistent with students working on a project that they consider to be relevant [74]. With that engagement, they also reported a sense of ownership or control over the project direction and experience. With continuing concerns about persistence in CS and other STEM disciplines, the role of project ownership may be key in connecting students with a sense of ownership over their learning. As the CS discipline faces an enrollment boom [15], there may be benefit from crafting other classes around this concept, such that the students themselves take ownership of their learning experience as part of responding to increased numbers. Outside of the academic setting, students may not be able to explore and to fail as supported in capstone projects, with the university and faculty as resources to recover from failure.

Chapter 4

Multiple Planes of Concern: A Study of Computer Science Professional Identity Formation through Changes in Participation-Based Concerns

The following chapter is adapted from a manuscript submitted September 30, 2018, to the Journal of Computer Science Education (CSE) [70]. Reviewer comments were received February 25, 2019, with an invitation to revise and resubmit the manuscript for publication.

Committee members agreed to accept the manuscript as a chapter in this dissertation research, despite the final acceptance not being completed at time of defense. Committee members were generous in their feedback and advice, including a request for inclusion of material describing the limitations of the chapter under review. Once the final manuscript is published, that version is considered as the fully peer-reviewed and accepted model, methods, and findings.

The current revision included in this dissertation attempts to weave together Rogoff's Multiple Planes of Development with Fuller's Teacher Concerns Model. Committee and reviewers see potential for benefit from this approach, as well as significant limits in how the application documented in this paper played out. My use of Professional Identity (PI) is as a construct that exists simultaneously in the personal, interpersonal, and community spaces. For the community of software engineers, this is the combined understanding of the ethical standards and behaviors expected of each member of the profession, evolving as technology continues to broaden boundaries of application. The interpersonal acting out of PI includes receiving others as professional in their behaviors, a willingness for collaboration, and a need for recognizing this as a transition from much of the individual labor required in undergraduate CS Education. As individuals interact

with expectations of the professional community, and transition into collaborative teams in the CS Senior Projects course, they take on roles and engage in practices resembling those of professional software engineers. As they take up these roles and activities, they participate in being software engineers while simultaneously shaping those practices and the very meaning of what doing software engineering is.

The dataset gathered for this dissertation research includes student interviews and academic artifacts from multiple iterations of the CS Senior Projects course. My initial work in analyzing this dataset, as presented in this chapter, struggle with applying the Multiple Planes of Development model effectively. A significant challenge arises in that the interviews and many of the artifacts capture the perspective of an individual. These lend themselves to focusing heavily on the personal plane, especially if the working use of PI is collapsed to only be considered as occurring within an individual.

One method for continuing the emphasis on interpersonal and community planes of enacting software engineering may be to extend the dataset collection process. In O'Connor's work, for example, remote team members required telecommunications systems for team meetings, and the research benefited from recordings of these virtual sessions [62]. At a recent conference, I spoke with another researcher who is exploring team dynamics changes over time in a similar capstone course by inviting teams to commit to using a digital camera to record their weekly meetings. The researcher discussed that teams were self-conscious early on when being "filmed," though they later relaxed and ignored the camera while still being diligent in capturing the dataset. This approach is promising, as the student teams join the researcher in producing the dataset, rather than requiring the researcher to be constantly present in making observations.

A recommendation from a committee member is for me to shift my focus from development of Professional Identity, which may be confused as a purely individual endeavor, toward team socio-genesis, or the development of a team identity and cohesion. The CS Senior Projects course under investigation lends itself well to this transition of my analysis, as the course sits at the boundary between university and industry settings. For this instance of the course, students previously have

limited to no experience engaging in collaborative team work. Most students anticipate graduating into a full-time profession as software engineers. Thus the capstone projects are a space for trying on roles and practices that are authentic for their eventual professional selves, while linking success to the collaborative team performance. This transition in focus offers an application of my framework wherein I can discuss the contextual setting of the course within the university and the larger professional community of software engineers. The CS Senior Projects capstone presents specific structures and expectations for students, and just as importantly leaves parts for teams to decide. Within the space created by the course, student teams may thrive or struggle. My discussion can focus on the emerging team experiences as occurring within the course structure, and as supported by external project sponsors. At this stage of data gathering, my work will still draw on individual interviews and course artifacts, so will still have limits in terms of evidence presented.

My initial foray into using Rogoff's methods as captured in the accompanying chapter struggles by focusing too heavily on individuals and individual perspectives, at times falling into a psychological perspective over the sociocultural view. I believe that the addition of Fuller's Teacher Concerns Model to Rogoff's Planes of Development is still an interesting approach worth considering, and I anticipate that a focus on team sociogenesis will aid in maintaining the sociocultural approach. My work is one step in the process of exploring the impact of the CS Senior Projects capstone experience on forming teams and team members who are ready for the transition into the workplace. While this work continues forward, the accompanying chapter represents a point in the development of my understanding of theories and application through methods for exploring this fascinating area of transitioning teams and students.

4.1   Abstract

Professional identity formation is a crucial facet of Computer Science Education, as it contributes to persistence problems and the transfer of professional practices. To study professional identity formation in Computer Science, I combine Rogoff's Multiple Planes of Development analytical framework with Fuller's Teacher Concerns Model, resulting in the Multiple Planes of Concern

framework. This approach fuses the developmental planes of personal, interpersonal, and community, with expressions of confidence and concern across self, task, and outcome. The resulting model provides a theoretical foundation for investigating developing practices and early professional identity formation. I demonstrate the proposed framework through a case study of an academic-year-long Computer Science capstone course. The case study explores changes in expressed and evidenced confidence and concerns that accompanies developing practices and professional identity formation during the university-to-work transition of students.

4.2   Introduction

Computer Science (CS) has an ongoing persistence problem with recruiting and retaining women and minorities (cf. [10, 14, 55, 85]). The decisions around enrolling and staying in computing are complex. Margolis and Fisher determined that loss of confidence accompanies loss of interest, leading up to the decision to withdraw from a university CS program [55]. They refer to the interaction of confidence and interest as a "nexus" because their work was not sufficient to determine causality between the two. According to engineering education research, persistence is a cultural issue [84], one which is linked with the learning process and identity formation [91]. Tonso presents her core claim:

> [I]dentity and learning prove interconnected.... Within this tradition, learning is itself conceptualized as a change in identity that comes with participation. As learners move from novices to mature practitioners, they likewise shift from peripheral participation to fuller participation; they undergo identity transformations and their identifying with a community of practice becomes a central part of the learning that takes place [91].

Different learning models support varying methods for intervening to improve persistence for all in CS. Rogoff identifies three approaches to theories of learning [78]. These include development as *transmission*, *acquisition*, and *participation*, each shifting the perceived active role that drives learning:

> The way that researchers and practitioners have traditionally gone about under-

standing children's development involves assuming a boundary between children's learning and the sociocultural world. External information is conceived as crossing a boundary to be stored internally, with either the individual or the environment as the active agent responsible for moving new materials across the boundary.... From the transmission perspective, the environment produces learning by inserting information; from the acquisition perspective, the individual is responsible for gaining the skills and information.

However, the boundary between individual and environment disappears if development is viewed as transformation of participation.... [S]ociocultural activity – rather than the individual – [i]s the unit of analysis, with three lenses showing three different planes of analysis of the role of individuals, interpersonal relations, and community activities [78].

With a *transmission*-based view of learning, the teacher and learning environment become the focus for interventions. For an *acquisition*-based view of learning, the learner and their process of constructing knowledge from their experiences are important. The focus on sociocultural activity, with the multiple planes of development, links transformation of participation with progression across the individual, interpersonal, and community planes. Students have a role, and they directly interact with others, and the larger professional community of practice influences the process. This third model of development offers a holistic perspective on learning. Khoo et al. refer to Rogoff's third method as the Multiple Planes of Development analytical model [49].

By recognizing persistence issues as cultural, a method is needed that supports analysis across the culture of the professional community. Multiple Planes of Development, which supports analysis across personal, interpersonal, and community planes, holds strong potential as a method for studying how learners enter the CS professional community of practice and form a professional identity.

From a situated learning perspective, students should adopt and demonstrate professional practices as they progress along their trajectory of participation. Bareiss, et al. found that CS Master's students failed to transfer best practices of software engineering from their coursework into a self-directed project [4]. The missed transfer of practices is another indicator of poor professional identity formation.

Ben-Ari claims that situated learning and communities of practice cannot be directly applied

in CS university courses, because the trajectories of students after graduation are too diverse to fully integrate into a single legitimate classroom experience that fully supports all future needs [7]. In a later clarifying work, Ben-David Kolikant and Ben-Ari suggest an alternative model for thinking about creating a professionalizing experience within the classroom [8]. They perceive a cultural clash between student expectations and instructor expectations for the learning environment. The concept of culture clash as part of CS education is not new [87]. Ben-David Kolikant and Ben-Ari recommend creating a space that can be considered as legitimate for the CS learners, acknowledging that they enter with a level of confidence, familiarity, and comfort in working with technology. The learning space should also pull in aspects that are legitimate to the professional culture of the larger CS community. The resulting space becomes a *Fertile Zone of Cultural Encounter* or *FZCE*, effectively bridging the educational and professional spaces by creating a sub-community that is both learning and professionalizing.

4.2.1   Professional Identity Formation

Tonso connects an individual and a professional community of practice through Professional Identity; for the profession of engineering, it is Engineering Identity [91]. "A professional identity is critical to a person's sense of self: It is about connecting with roles, responsibilities, values, and ethical standards unique to a specific profession" [41]. How is professional identity situated for the CS profession?

Cogan presented characteristics that accompany maturation of a profession, including credentials and formal bodies for monitoring ethical behaviors [20]. He considered computing to be one of the occupations emerging from World War II, and as such still in the process of maturing into a full profession [20]. Comer postulates that CS is in an "identity crisis" [31]:

> The field is in a malaise, experiencing an identity crisis and questioning its value....
> Perhaps CS is like a teenager – not fully mature, and not yet confident about its
> place in the world [23].

The existing stereotypes around the CS profession are predominantly established [30], and as such

will require significant focused effort to enact change. Rising CS graduates who do not match the perceived cultural norm struggle to form their personal sense of identity.

Within the CS discipline, professional identity formation is a recent topic of interest, from introductory CS coursework [75] through to capstone coursework [89]. From a workshop on introducing ethical expectations in undergraduate CS classes, contributors noted the importance of clarity in how ethical expectations are presented to students [86]. Further, the authors noted the need for expectations to transition from academic ethical practices to professional ones, perhaps mirroring student progression from early coursework toward a capstone experience [86].

A survey of students who withdrew from CS noted that the most frequent reason cited by women for leaving was "I did not feel as if I belonged" [9]. A concluding comment from the authors posed several questions:

> The people who leave are the people who later described in great detail about being cared about in other majors. Since so many of the retention initiatives have to do with connecting to and networking with people, how *does* this fit with our culture? To what extent is this true across CS departments in general and is there energy within the departments to make room for people who want strong bonds with people? [9, emphasis in original].

Next, I examine efforts around professional identity formation in more established professions.

4.2.2   Professional Identity Formation in Other Professions

Medical, legal, education, and more recently, engineering professions have established professional communities. Many of these professions have processes for licensure and ethical behavior review boards, matching maturity indicators from Cogan [20].

From medicine, Orenstein presents an overview of a medical journal's special issue on professional identity development for students: "More than just inspiration, professional identity formation - PIF - is increasingly seen as a crucible in which doctors become tempered against burnout, cynicism, and ethical decay" [64]. Orenstein considers professional identity as correlating with resiliency and preventing burnout.

For law, [94] reviews a course from Neil Hamilton introducing professional identity for legal students. The course includes guided reflection and mentoring to encourage students to make decisions about what is personally meaningful and fulfilling about their chosen profession. The course includes personality assessments and teaches emotional and social intelligence. Ward notes the professional identity course has improved the transition from university to the workplace. The metric used is employment rate at nine months after graduation, which improved from 59.6% in 2012 to 79% in 2015 [94].

For education, more extensive research into professional development of educators examined teacher concerns as evidence of staged progression of maturity [35]. The researchers started with pre- and in-service teachers. In early work, researchers analyzed teacher observations when reviewing video of their own classroom instruction practices. In subsequent iterations of the study, teachers were given a blank page and a prompt to write freely about what they were concerned about with respect to teaching. This method is Teacher Concerns Statements (TCS) [59].

Fuller considered concerns to occur in stages, noting that early stages of concerns prevented the teacher from focusing on later stages [35]. Given the prompt, "When you think about your teaching, what are you concerned about?" [37], analysis of responses supported a three-tiered concern model:

(1) Self-Oriented Concerns: About role (where do I stand?) and adequacy (how adequate am I?), also referred to as *survival concerns*

(2) Task-Oriented Concerns: About teaching (are pupils learning what I'm teaching?)

(3) Outcome-Oriented Concerns: About pupil needs (are pupils learning what they need?) [38]

Later research explored generalizability of Fuller's Teacher Concerns Model to other disciplines, such as training health professionals [56]. The concepts around the model continue to be used in education [24]. One branch of work adapted the Teacher Concerns Model into the area of innovation adoption [59]. This work contributed to Stages of Concern about an Innovation, part of the Concerns-Based Adoption Model, or CBAM [44].

Generally, Schneider points to professional identity awareness and support as something employers and HR departments can offer new hires in any profession as a strategy to combat turnover [82]. Schneider specifically links this strategy to addressing self-oriented concerns experienced by the new employee: "The best thing we can do is to be mindful of these insecurities and reaffirm our new employees of their decision to join the organization. Be prepared for their arrival, make introductions, schedule regular meetings to discuss their experiences and feedback, and help them establish a professional identity" [82].

4.2.3   Studying Professional Identity in Computer Science

Professional identity and the process of its formation are occurring on a subconscious level [31], with reflection offering time and space for individuals to revisit experiences and to bring the unconscious process to conscious verbalization. The integration of reflective observation as a step in learning cycles [51] has been included as a key phase of experiential learning [1].

Trede included the importance of learners as having opportunity for engaging in practices that will motivate discourse about how to apply knowledge, coupled with the space to engage in discourse [92]. Trede developed a program she referred to as "work-integrated-learning." The research team trained host professionals in how to hold student discussion sessions separate from work tasks, effectively creating a space for learner discourse to occur. This is consistent with Tomer and Mishra and their model of *identity morphing*, as capstone students have teams and project mentors providing a similar space for discourse about practices [89].

In a similar study of CS capstone course influence, Parker engaged students in self-reflection through semi-structured interviews [66]. He focused on the role of statements of confidence and concern in thematic analysis of interview transcriptions. The work concluded that CS students do experience an emotional roller coaster. The use of confidence and concerns in reviewing student experiences is supportive of the methods from Fuller [38].

4.2.4   Extending Rogoff's Multiple Planes of Development Analytical Framework

With qualitative data from student self reflections, the analytic framework from Rogoff [78] offers an approach for organizing the changes in practices evidenced by study participants. The framework allows flexibility in adapting the approach based on the specific study and conditions that are under investigation.

Rogoff proposed her framework for analyzing evidence of changing participation across multiple social planes [78]. Namely, the interdependent lenses of analysis are:

(1) The community plane

(2) The interpersonal plane

(3) The personal plane [78]

This method of inquiry supports research into activities of participation; changes in the activity, its purposes, and people's roles; relationships between activities; and ways that prior participation prepares for future expectations [78]. Each lens is considered during analysis, foregrounding that aspect of participation while still acknowledging influences from the other lenses [78].

4.2.4.1   Limits of Rogoff's Model

In an application of Rogoff's Multiple Planes of Development framework, researchers noted that "it is a useful tool for responding to the complexity and 'messiness' of real life socialcultural (sic) contexts" [49]. Yet the researchers struggled to integrate the lenses when focusing on a specific analytical lens, despite acknowledging the interconnected nature of the framework [49]. The resulting analysis is deficient, or at least incomplete, in not offering an integrated understanding of the interplay between these layers of analysis.

4.2.4.2   Limits of the Teacher Concerns Model

In revisiting Fuller's original Teacher Concerns Model, Conway and Clark provided a survey of critiques about the work of Fuller's team [24]. Focus on *person* over *societal role* was noted as problematic, resulting in "personalistic pedagogy rather than inquiry-focused pedagogy" [24].

Conway and Clark still found the concerns model beneficial, although they identified a dual nature of concern development as both "inward and outward" [24]. They agreed with Fuller's model as moving outward from self to outcomes, yet also noted an increased capacity for inward reflection and introspection about self-identity with respect to the profession.

In their conclusions, Conway and Clark noted "it is helpful in understanding the patterned complexity of learning to teach to shift between each of these figures, remembering that each is [back]ground to the other" [24]. This conclusion parallels Rogoff's model, with multiple planes that remain visible in the background while foregrounding a specific plane of analysis.

4.2.4.3   Combined into Multiple Planes of Concern

I propose an extension to Rogoff's framework, aiming at the conditions of concern that underpin the changes in practices. Concerns are part of the changing ways of participation available to researchers in applying Rogoff's framework.

To extend Rogoff's Multiple Planes of Development analytical framework with Fuller's Teacher Concerns Model, I apply the three orientations of the Concerns Model to each of the three analytical planes of development. The result is a three-by-three grid of concerns across planes. This resulting framework, Multiple Planes of Concern (MPoC), can serve as a method for analysis, for organizing information, and for conducting thematic analysis on a data set of qualitative data. Example data extracts for each sector of the resulting grid appear in table 4.1.

To demonstrate how the MPoC framework assists in conducting a qualitative investigation around identity development, I apply it to a study of professional identity formation in CS.

In computing education, community and interpersonal settings for learning may be overlooked

Table 4.1: Sample results from applying Multiple Planes of Concern to the qualitative data about student reflections in thematic analysis. Coding for planes of development can be performed independently of coding for confidence and concerns. Here, samples of each sector are provided. The next task is for researchers to consider what is salient about the data linked to other sectors, what stories or explanations or insights emerge from combining the data.

Plane	Concern/ Confidence	Example Response
Personal	Self	"Expressing what I think should be done instead of being told what should be done" – [Cayden, Team Gamma, Personal Goals 1]
Personal	Task	"To fill in any gaps ... in regards to software development. I know how I write software when working on my own projects on my own time, ... but there is lots that I have yet to do" – [Dre, Team Gamma, Personal Goals 1]
Personal	Outcome	"Through reading and talking to people I've learned a lot about the CS profession and what routes that I can take as a computer scientist." – [Manuel, Team Vega, Personal Goals 3]
Interpersonal	Self	"We learned to not be afraid to ask for help.... It may seem intimidating to ask somebody else on your team for help" – [Team Gamma, Lessons Learned]
Interpersonal	Task	"Patrice and Marie were assigned [feature] for our project and were not able to deliver on what they said they would deliver on." – [Owen, Team Alpha, Peer Evaluation 4]
Interpersonal	Outcome	"Learn how to manage a relationship with a sponsor and their expectations" – [Brian, Team Gamma, Personal Goals 1]
Community	Self	"Learn more about different routes for CS majors post-graduation" –[Brian, Team Gamma, Personal Goals 1]
Community	Task	"Better understanding of software development. Recognize common technical/communication pitfalls (solutions on how to avoid them)" – [Franz, Team Gamma, Personal Goals 1]
Community	Outcome	"Currently my past experiences with projects are that they are [not] meaningful or really have that any great substance to them" – [Nigel, Team Alpha, Personal Goals 1]

[5]. Use of these various planes of organization and analysis supports deeper insights into challenges and opportunities for supporting and sustaining learning in computing. Development challenges may be particularly salient for study at liminal transitions, as with entering college or moving into the workplace [5, 6, 93].

The following case study applies the MPoC model in analyzing a data set from a CS Senior Projects capstone course.

4.3   Materials and Methods

This case study provides deeper insights into the overarching question, "How does the CS Senior Projects course influence students during the university-to-work transition?", through the reflection assignments and open-ended survey questions that students completed during and after their participation in the course. Specifically, this work investigates the research question, **RQ3: What is the interplay between planes of development and stages of concern as underpinning professional identity formation?** My use of the MPoC model in analyzing the data set supports deeper discussion into the course influence from the students' perspectives.

4.3.1   Context: CS Senior Projects Course

For this case study, my data draws from the CS Senior Projects capstone course during the 2016-17 academic year. Students completed reflective assignments as part of the course, both individually submitted and as group work. External project sponsors are recruited from industry and the academic community of the university. Each sponsor brings an idea that might be solvable through a software development project. After meeting with project sponsors during the first week of classes in August, students submitted their top five project preferences. The course instructors assigned students to teams based on those expressed interests. Project sponsors evaluated each team four times during the academic year.

Student teams met weekly with a class teaching assistant (graduate student with prior professional experience in software development), and regularly (about biweekly) with the project

sponsor. Most projects adopted an Agile methodology with a sprint iteration of two to four weeks. The demographic breakdown of the 88 students enrolled in the 2016-17 academic year appears in Table 4.2, based on a public release request from university records.

Students assess courses and faculty (Faculty Course Questionnaires, or FCQs) at the end of each semester, with results publicly available after grades are finalized. The FCQ survey includes the question, "This course prepared me for my chosen career," with responses on a 6-point Likert scale from "strongly disagree" to "strongly agree." Because the course spans two semesters, student assessments occurred twice. At the midpoint of the course, and at the end of the course, responding students tended to agree that the course prepared them for their professional career (see table 4.3).

4.3.2 Qualitative Data Sources

The case study data set draws from individual and group assignments completed for the CS Senior Projects course during the 2016-17 academic year. These assignments include the following:

(1) Project Preference Survey: Students provide top five project preferences, and a note on preference motivation.

(2) Personal Goals: Students submit personal goals, including self-reflection on progress toward their goals, three times during the academic year.

Table 4.2: CS Senior Projects population demographics for the 2016-17 academic year.

Demographic	Breakdown				Total
Gender	68 men			20 women	88
Ethnicity	64 White/Cauc.	10 Asian	6 Hispanic	8 other/no response	88
Age	75 at 23 or younger			13 at 24 or older	88
1st Generation College Student	80 2nd generation or later			8 1st gen.	88
Major	81 Bach. of Science in Comp. Sci.		4 Dual BS/MS in Comp. Sci.	3 Bach. of Arts in Comp. Sci.	88

(3) Career Influence: About one year after completing the projects, students completed an online survey to grant consent for research use of their classwork. In addition, the survey asked, "How has your career been influenced by your senior project experience?" Responses are open-ended.

(4) Team Risk Assessment: Early in the project, each team submitted a risk assessment with mitigation plans.

(5) Team Peer Evaluations: At four times during the academic year, each team member submits an evaluation of how balanced project contributions are. The peer evaluation categories are included in Appendix D.

(6) Sponsor Evaluations: At four times during the academic year, sponsors complete an evaluation of how the team is performing.

(7) Team Test Plan Review Minutes: In the second half of the project, teams review the project test plan. Minutes capture deficiencies and action items discussed by the team.

Table 4.3: CS Senior Projects course survey responses to the question of capstone course influence on career preparations (88 students in course, 68 (77.3%) responded for fall, 59 (67.0%) responded for spring). The majority of students tend to agree that the CS Senior Capstone course prepared for their chosen career.

		Fall 2016		Spring 2017	
		Count	*Percent*	Count	*Percent*
This course prepared me for my chosen career.	**Strongly Disagree**	2	*2.94%*	1	*1.69%*
	Disagree	3	*4.41%*	1	*1.69%*
	Somewhat Disagree	3	*4.41%*	1	*1.69%*
	Somewhat Agree	8	*11.76%*	5	*8.47%*
	Agree	12	*17.65%*	13	*22.03%*
	Strongly Agree	40	*58.82%*	38	*64.41%*
	Total	68	*100.0%*	59	*100.0%*

(8) Team Lessons Learned: At the end of the project, each team submits a list of "lessons learned" from their project experience. The list is generated by the team in a group discussion.

The individual and group assignments invited students to reflect on their project experience. The resulting open-ended responses are the qualitative data for investigating the influence of the course across the personal, interpersonal, and community planes of development. Questions related to goals and outcomes contribute to analysis of confidence and concerns.

Student data was originally submitted for the academic purpose of assigning a grade. As such, each team member was later asked to grant consent for use of their individual and group work for research purposes. To be eligible for consideration, all team members must have granted consent for their academic coursework to be used for research.

4.3.3   Focal Student Teams

For this case study, three of the 16 teams from the 2016-17 academic year were selected as focus teams. Of the 16 teams in the cohort, five teams fully agreed to participate. Three of those consenting teams, referred to for this report as Teams Alpha, Beta, and Gamma, included responses about how their project experience influenced their career, submitted about one year after graduation. From the two teams not included in this case study, none of the team members completed the post-project survey question. Team demographics for the three focus teams appear in table 4.4.

Teams Alpha and Beta included a mix of men and women, and Team Gamma was all men. Team Beta was the first project preference of all team members, Gamma was second and third preferences, while Alpha was a mix of first to fourth preferences. Team Alpha worked with an academic sponsor within the university, and Teams Beta and Gamma both worked with industry sponsors outside the university.

4.3.4 Thematic Analysis by Multiple Planes of Concern

Thematic Analysis [11] is a method for exploring large qualitative data sets. With qualitative data, interpretation facilitated through researcher discourse aids in identifying meaningful trends and themes. For this case study, I used thematic analysis with a top-down approach, in that the initial set of themes came directly from the MPoC model. These themes then serve as guidelines for readers in reviewing the qualitative data for the study.

To apply the MPoC model in thematic analysis, researchers read and reread the qualitative data, immersing themselves in the data. Readers identify data extracts that capture cohesive ideas with respect to the target thematic codes. Coding is then performed by assigning data extracts across the three planes of development and the three stages of concern/confidence. After

Table 4.4: Demographic data for the three focus teams from the 2016-17 academic year of the CS Senior Projects course. All teams submitted group work for Project Lessons Learned, Test Plan Review Minutes, and Peer Evaluations 1, 2, 3, and 4. All teams were assessed four times by their sponsor, as Sponsor Evaluations 1, 2, 3, and 4. Individual assignments include: 1. Project Preference Motivation, 2. Personal Goals 1; 3. Personal Goals 2; 4. Personal Goals 3; 5. Career Influence Reflection. Not all students submitted all individual work, as noted in the table below.

Team	Student Pseudonym	Project Preference	Individual Work Submitted
Team Alpha Academic	Marie	2nd	All
	Nigel	3rd	All
	Owen	1st	All
	Patrice	1st	All
	Quinn	4th	All
Team Beta Industry	Vince	1st	All
	Wayne	1st	All
	Xavier	1st	All
	Yvonne	1st	Missing "Personal Goals 3" and "Career Influence Reflections"
	Zahara	1st	Missing "Career Influence Reflections"
Team Gamma Industry	Andrew	2nd	All
	Brian	3rd	All
	Cayden	3rd	All
	Dre	2nd	Missing "Personal Goals 3"
	Evan	3rd	Missing "Personal Goals 3" and "Career Influence Reflections"
	Franz	2nd	Missing "Career Influence Reflections"

applying these themes across data extracts, readers met to discuss what each noted as meaningful. Differences in opinions are an important aspect of exploring the complexities of human expression and understanding nuances present in the data. The ensuing discussions about coding challenges are an important part of organizing data extracts into themes.

Refer to Appendix C for guidelines on how to understand the nine sectors resulting from the intersection of the planes of development with the stages of concern. Readers raised an important distinction, that the personal plane focuses generally on roles and tasks, while the community plane focuses specifically on roles and tasks in the CS profession. This distinction was challenging to maintain at times, and some readers noted that they considered marking extracts on both planes.

Next, readers considered how the planes of development (personal, interpersonal, and community) intersected with the stages of concern/confidence (self, task, and outcome). For example, they hold a team or individual in focus while examining changes in concern across developmental planes.

Use of the MPoC model supports exploring complex qualitative data that may represent "messy" [49] situations and longer intervals of change. The model focuses on how concerns are expressed and how those expressions change. The analysis highlights some salient insights from the three focal student teams and their experiences.

From Rogoff, "focus on one or another plane of analysis is for the purposes of study and communication. The three planes cannot be isolated, and none is primary except with regard to being the current focus of attention, when we can focus on one or another, keeping the others in the background for our analysis" [78]. It is important to consider the various planes, and to watch for influence across planes. The focus on confidence and concerns serves to organize data within and across planes.

4.4   Results

These results represent specific insights gleaned from applying the MPoC model to the qualitative data set gathered from the CS Senior Projects course during the 2016-17 academic year. For purpose of this case study approach, I first focus on a pair of assignments that were impactful

for professional practices. Second, I focus on Marie[1] from Team Alpha and her growth and development as evidenced by her changing concerns. Finally, I compare growth of Team Beta with evidence of stability of Team Gamma, as represented in the MPoC framework. By tracing these threads across the data set, I explore deeper insights of the case study and how the framework can benefit qualitative analysis of professional identity formation.

4.4.1   Planning versus Practice

Bareiss and Katz were frustrated by the failure of CS Master's students to make use of software engineering best practices on the final project [4]. They surveyed students about their perceptions of project shortcomings. The authors noted the lack of transfer as a significant frustration of the course, despite their evidence that students were able to identify practices that were not integrated into the project.

For the CS Senior Projects capstone with BS undergraduates, similar shortcomings are expected. Rather than focus on these as evidence of failed transfer, instructors leveraged the disconnect between planning for best practices and adaptation for the practical side of running a longer project. In the first semester of the projects, each team prepared a project test plan. The plans often included automated continuous integration and regression tests, as well as plans for full formal acceptance tests. Rarely do teams actually follow these original plans, especially as they balance the day-to-day running of their project with demands from other courses and time constraints on their project work.

Knowing that many teams will have adapted their practices in response to the various constraints on their projects, instructors tasked teams to conduct a test plan review early in the second semester of the project. With this assignment, teams directly confronted the disconnect between what they identified as appropriate best practices early in the project, and the actual practices they are engaging as the project progressed.

From the meeting minutes of these test plan reviews, actions taken generally fall into several

---

[1] All student names have been replaced by pseudonyms to deidentify data extracts.

categories. First, when teams recognize the deficiencies in their testing practices, some recommitted to the original testing practice: "Everyone writes tests even if they are very simple tests to ensure best practices" – *[Team Gamma, Test Plan Review Minutes]*.

Second, teams considered adaptation of practices based on their current perspective of practically running a resource-constrained project. "With the short amount of time left for the project, we will just be testing the essentials" – *[Team Gamma, Test Plan Review Minutes]*.

Third, teams strike a balance between their original (perhaps naive) plan and the practical aspects of a resource-constrained project. Teams often were inventive in creating solutions: "[We will] have a ... testing coding party. Spend 1 hour a week writing tests per team member" – *[Team Beta, Test Plan Review Minutes]*.

The use of creating test plans, and reviewing them after progressing deeper into the project implementation, yielded practical adaptations of best practices in testing. Many teams initially expressed discomfort at the disconnect between their plan and their practices. They often emerged from their group discussion with a more realistic balance of appropriate practices. Perhaps more important, team members often engaged in discussions around the "why's" behind the practices. Through these discussions, they then based their decisions on practices to abandon and which to retain, on what benefit the practice would have on project outcomes. This deeper appreciation for practices is strong evidence of transition from task-oriented to outcome-oriented discourse.

4.4.2 Marie's Development on Team Alpha

Marie was one of five students assigned to a project sponsored by a group within the university. Her development story over the academic year offers an individual perspective on both the Multiple Planes of Development and the Concerns Model. As such, Marie's story serves as an application of the MPoC model across the combined sectors.

At the start of the project, Marie's personal goals addressed her limited experience with teamwork and project tasks, all of which map to task oriented concerns across the planes:

(1) [Interpersonal/Task]: I want to get some experience working in a team

(2) [Personal/Task]: Experience making a working app

(3) [Personal/Task]: Managing a database

(4) [Community/Task]: Learning more about professional work experience – *Marie, Personal Goals 1*

At the first peer evaluation cycle, Marie ranked her contributions far below her peers. Two of her peers also rated her contributions as low, although not as harshly as Marie rated herself. Team members indicated that Marie was soft-spoken and that she would not often contribute to team meetings, which can indicate introverted tendencies. She may have struggled with impostor syndrome or similar self-oriented concerns.

On her second personal goals submission, Marie noted:

> I feel like my goals were not achieved to the extent I would like. My group works well together, and I'm glad I got experience working with them, but I know I could have done more to contribute to the project than I did. Though I did get exposure working with [feature A], I personally did not contribute to it. [Feature B] will be the primary focus of next semester. My goal for next semester is to work more on the coding development side of the project – *[Marie, Personal Goals 2]*.

Her focus on personal contributions, or what she perceived as a lack thereof, matches more strongly with self-oriented concerns on the personal plane. Self-oriented concerns can prevent an individual from engaging with the work at hand, leaving the individual frustrated [37]. Fuller suggested that arousal of task-oriented concerns can help move the progression of the individual forward.

While Marie did not discuss her emotional state in her personal goals submissions, she did set her goal of "work[ing] more on the coding development." This shows a conscious effort to transition into task-oriented concerns by committing herself to engaging in the writing of software for the project.

Marie continued to be her harshest critic, from peer evaluation submissions through the final round of evaluations. The final personal goals submission occurred a few weeks before the close of

the project, offering some insight into Marie's state of mind as the project was wrapping up.

> I have definitely learned a lot more about [technical topic]. I have gained more experience working with a team, and it is nice to see the results of our programming knowledge – *[Marie, Personal Goals 3]*.

Marie spoke about the team and "our programming knowledge," a contrast to her self-focus at personal goals 2. This is strong evidence of progression both in terms of her confidence and her capacity to focus on her contributions as part of a team effort.

With the final peer evaluation, comments from Marie and several team members offer deeper insight into team conflict and (at least partial) resolution. Because of her goal to develop software for the team project, Marie worked directly with teammate Patrice on a section of the project. This may represent a significant effort on Marie's part in overcoming some of her introversion.

Owen claimed, "Patrice and Marie were assigned [feature development] for our project and were not able to deliver on what they said they would deliver on" *[Owen, End-of-Spring Peer Evaluation]*. Marie shared additional insights: "I wish I'd had more help from Patrice. Her task was difficult, but she did not communicate her issues or progress to me" *[Marie, End-of-Spring Peer Evaluation]*. Owen also said, "Marie did far more work on the application than Patrice did but neither were productive throughout the semester until the final weeks" *[Owen, End-of-Spring Peer Evaluation]*.

In the end of spring evaluation, Marie marked herself as equal to her peers, while reducing her assessment of Patrice. On its own, this action matches expectations, given that Patrice and Marie were collaborating, and Patrice failed to fully disclose her struggles. As a result, the team felt that the work the pair had completed was deficient. Marie's earlier self-concerns and her significant effort to move to task-concerns culminated in her owning her role in the collaborative effort. Her earlier self-denigration in completing peer evaluations is gone in the final assessment, as she ranked herself equal to her peers. Further, she had confidence in her contributions such that she reduced her assessment of Patrice.

In her reflections one year after completing the project, Marie shared:

> I have been hired by the [university sponsor] to complete the project. The things I learned working with my team helped prepare me for understanding all parts of the project and the full procedure for creating a finished product – *[Marie, Reflections on Career Influence]*

Marie ended the project with deeper understanding of the entire system and greater confidence. She attributed this job move to the increased confidence she gained from stepping up on the project.

In the end-of-project team discussion about what lessons were learned from their experience, the team included this comment:

> [You] shouldn't be intimidated, [because you] gotta start somewhere – *[Team Alpha, Lessons Learned]*.

While not attributed to any one team member, Marie's experience may have served to drive this lesson home for Team Alpha.

4.4.3 Development of Teams Beta and Gamma

Following the methods from Fuller [38] and Hall [43], categorization of concerns offers potential insight into individuals and groups. Parsons noted an important distinction limiting how far analysis and comparison can go when relying on qualitative data, as absence of reflection on concerns may not represent the absence of concerns [73].

A rudimentary comparison of artifacts from Teams Beta and Gamma demonstrates the capacity of the MPoC model in differentiating team development. See table 4.5 for the results of thematic analysis, with breakout of data extracts across the sectors of the MPoC model. In coding artifacts from Team Beta, readers identified and coded 84 extracts across the MPoC model, with 59 extracts for Team Gamma. The thematic coding process yielded a roughly consistent ratio of extracts across developmental planes between personal, interpersonal, and community for the two teams. For their stages of concern, however, Team Beta is strongly in the self- and task-oriented concerns across all planes, with limited development within each plane. Team Gamma demonstrates more developmental evidence in transitioning from task- to outcome-oriented concerns.

Stepping back from the numerical representation of the data set, the content from student reflections is consistent with Team Beta's greater growth and development. In contrast, Team Gamma is stagnant in task-oriented concerns. Perhaps the strongest evidence to this effect appears in the external evaluation provided by the two project sponsors. The sponsor for Team Gamma noted repeatedly that he desired for the team to provide more consistent communication. This occurred in three of the four sponsor evaluations. In all three cases, the sponsor noted that he wanted to hear from Team Gamma more often. As soon as the team received their sponsor evaluation, they reached out to provide the desired update; in each case, the sponsor immediately sent an updated assessment with an improved grade. Team Gamma did not seem to change their approach to communication, despite the repeated issues encountered. The team listed communication in their "Lessons Learned" submission, noting: "We have learned that communication is a big part of a large project." Yet this statement was coded to task-level concerns on the community level, as the focus is on communicating and not the outcomes.

Table 4.5: Results of thematic analysis by data extracts for Teams Beta and Gamma. Team Gamma had fewer coded extracts than Team Beta (59 to 84), which makes direct comparisons difficult. Looking solely at the developmental planes (rows), there is no statistical difference between the distribution of extracts of the two teams ($\chi^2 = 0.0679$, 2 degrees of freedom, p = 0.97). Only considering the stages of concern (columns), the two teams are statistically different ($\chi^2 = 8.7597$, 2 degrees of freedom, **p = 0.013** <0.05). Team Gamma focused more on self- and task-oriented concerns, while Team Beta included greater focus on outcome-oriented concerns.

Team Beta		Concerns			Total by Plane
		Self	Task	Outcome	
Planes	Personal	5	7	5	17
	Interpersonal	6	12	12	30
	Community	3	22	12	37
Total by Concern		14	41	29	Total: 84
Team Gamma		Concerns			Total by Plane
		Self	Task	Outcome	
Planes	Personal	9	2	0	11
	Interpersonal	1	15	5	21
	Community	7	17	3	27
Total by Concern		17	34	8	Total: 59

In contrast, Team Beta's team lead, Yvonne, listed sponsor communication as a concern in her first personal goals assignment: "Develop communication skills in working with a nontechnical sponsor". Sponsor communication was listed on the team risks as important, with Yvonne engaging in plans for how to assist the non-technical sponsor in understanding the project.

While Yvonne as team lead provided a clear initial emphasis on communication, Zahara also noted in her personal goals a desire to improve communication with a non-technical sponsor. Zahara's first personal goal was to "get experience communicating technical concepts with non technical people". At her second personal goal submission, she noted:

> I have ... gotten a lot better at communicating technical things to [sponsor] because in order to tell her what I have been doing, which is very technical, I have had to put my work into layman's terms without dumbing it down too much. I feel like this has really improved because I used to explain things so that they sounded really simple when they really were not. Now I am able to give more detail about what a technical task entailed while still communicating it in a way that can be understood by someone with little technical background – *[Zahara, Personal Goals 2]*.

This is an example where the confidence/concern has shifted from the task-oriented focus of *communicating right*, which Team Gamma struggled with throughout the project, and onto an outcome-oriented focus of *communicating effectively*. Zahara has drawn out a distinction between methods for engaging a non-technical audience in a technical discussion. She now appreciates the significance of retaining complexity about the work performed, while still adapting her communication for the audience.

Team Beta generally had greater focus on project outcomes from the beginning. As an example, Vince set a goal to "Properly design and revisit designs to achieve the sponsor's expectations (I want to create their literal vision, make them go 'wow, that looks amazing!')" – *[Vince, Personal Goals 1]*. Readers coded this to the community plane and an outcome concern, as it focuses on addressing sponsor concerns through running the project.

Vince, Wayne, Yvonne, and Zahara all described a sense of connection to the sponsor and her "passion and vision" in their project preference motivation, indicating a strong personal connection during the initial project matching process.

The sponsor evaluations for Team Beta showed her own progression of concerns. In her first evaluation, she stated, "I don't honestly know the right questions to ask", which might represent self-oriented concerns about the project. Despite this concern, she also noted in the first evaluation that "they are doing a wonderful job trying to work with my ideas and desires and then telling me if they think they can do it or not."

In the third evaluation, Team Beta's sponsor noted, "they have done a fantastic job of not only adjusting [my expectations], but making me excited with what they can do with the time they have and new goals." The final evaluation is glowing with praise for the achievements of Team Beta:

> I cannot speak more highly of my team. From the start of the year to the end, they never ceased to amaze me.... My team took my idea that was disjointed, completely all over the place, with way too many paths and options, and turned it into this beautiful app that works!! They dealt with my lack of technical knowledge and verbiage and helped me understand what they were doing and how they did it. They helped me hone my thoughts into a feasible and realistic goal for the year and created a foundation for growth so I can continue this project. I gave them the freedom to create and they just scored! – [Team Beta, End of Spring Sponsor Evaluation]

The sponsor also noted the team's growth and development over the course of the project:

> The person they were at the beginning to who they are now are almost incomparable. They are not the same students that they were when we first met. – [Team Beta, End of Spring Sponsor Evaluation]

Where Team Gamma's sponsor evaluation repeatedly called for improved communication, Team Beta's sponsor evaluation focused on the impact the team was able to achieve. This is consistent with Team Beta's efforts to prioritize the tasks of professionally running their project, transitioning into the outcomes at that community plane.

4.5   Discussion

The MPoC model offers structure for investigating professional identity formation as changing concerns that underpin developing behaviors. The three focal teams each offer different insights for examining the role of change.

In the testing review minutes, teams directly addressed the disconnect between plans and the day-to-day practices of resource-constrained projects. By waiting until the second semester for the discussion, most teams had begun to adapt their software engineering processes in response to limited time and capacity as a team. These adaptations often were implemented without consciously considering best practices. As such, teams encountered a disconnect when asked to review their own testing plan. The process of reconciling the plan with their adapted practices yielded evidence that teams were focusing on the outcomes of testing practices.

With Team Alpha, the results focus on Marie and her shift from concern to confidence across multiple planes of development. The resulting story has an individual focus, while still integrating her role in a team setting and expectations from the professional community. She started the project with significant self-oriented concerns on multiple planes. Her mid-project personal goals update shows Marie's conscious decision to shift toward task-oriented concerns.

Fuller posited the structure of stages as a way to indicate that early concerns may prevent engagement with later concerns [35]. Marie's progress with engaging in productive tasks with the team supports Fuller's stage structure. She had to resolve, or at least decide to move past, her self-oriented concerns. In her follow-up reflection on the project's influence, Marie's confidence grew sufficiently for her to accept employment and to assume ownership of the full project. Marie's acceptance of a professional role based on her capstone project is solid evidence that her experience was meaningful.

Team Gamma is a stark contrast to Team Beta in terms of their development. Despite a focus on tasks as the *doing*-related concerns, Team Gamma did not present significant evidence of changing behaviors during the project. Their decisions related to communication are particularly puzzling, as a definite pattern shows their repeated struggle here. Meanwhile, Team Beta transitioned to outcome-oriented concerns across all planes. The sponsor evaluations across the project supplement the team artifacts, together painting a cohesive picture of the team development.

Both teams Beta and Gamma worked with industry sponsors, and both industry sponsors had limited technical background prior to starting the project. The teams worked on their projects

for the same duration. Yet Team Beta matured through the experience, and Team Gamma is unchanged. Several facts about the two teams may contribute to the developmental differences. Team Beta is composed of male and female students, and all five students received their first preference of project. Team Gamma is an all-male team of six assigned to their second and third project preference. All team members of Team Beta were in their fourth year of their Bachelor's degree studies, while two of the six team members on Team Gamma (Andrew and Franz) were in their fifth year.

None of these factors fully explains the developmental differences between the two teams, though project preference may be a contributing factor. This developmental discrimination between teams resulting from the MPoC model contributes to ongoing inquiry into how the CS Senior Projects course creates diverse learning opportunities for students.

The MPoC model supports discussion of an individual's growth with Marie, and comparison between Team Beta's growth and Team Gamma's stagnation. The framework is refined enough to examine individual and group development in a social context. It captures a dynamic range of growth for teams, from small change to greater transformation. MPoC offers insight into the potential for a specific course under study as a professional identity intervention.

4.5.1 Limitations and Future Work

While the framework is helpful in guiding organization of the data set extracts, it is still necessary for each research team to apply their insights and acknowledge their biases in identifying what is salient from the data. With that, they can then explore why development does (or does not) occur as anticipated.

This case study explores the depths of student perceptions of their experiences in a project-based experiential learning course at a single institution. While the focus supports insights and conclusions, this study does not speak directly to generalization of findings about capstone experiences to other institutions or learning experiences. The use of the MPoC model may be of benefit to researchers studying professional identity formation across a variety of learning experiences and

contexts. For the case study presented here, the model served to organize evidence within each plane, with critical focus on the early stage of self-oriented concerns expected for new entrants to a profession.

Fuller [38] supported later development of the Teacher Concerns Model into a quantitative Stages of Concern Questionnaire and the Concerns-Based Adoption Model [43]. Similarly, future work with MPoC may include developing a quantitative instrument to enumerate types of concerns expected at each stage and across planes of development. This paper focuses on early concerns oriented around self, task, and outcome. Hall extended that set with collaboration and extension concerns, representing higher levels of maturity [43]. There may be similar layers of later concerns that would be appropriate for integration into the work presented here. Those extensions would be helpful as focus shifts from seniors and early career professionals, onto later stages of professional development.

4.5.2   Conclusions

This work offers an extension of the Multiple Planes of Development analytical framework [78] with the structure from Teacher Concerns work [38], resulting in the Multiple Planes of Concern model. I applied the proposed model to an analysis of qualitative evidence from three focal teams of a CS Senior Projects capstone course. Through this application, I demonstrated how it contributes to studying professional identity formation as changing concerns that underpin developing behaviors.

The CS Senior Projects course served as a fruitful case study for applying the MPoC model. In the university end-of-class surveys, most students indicated they felt the course was influential in preparing for their careers. The case study goes deeper by explores specific qualitative evidence of that influence. The MPoC model offers the following contributions:

(1) Early concerns may limit capacity to engage in later concerns.

(2) Student development and learning is an ongoing process.

(3) Both the planes of development model and the stages of concern model contribute to the analysis, with insights bridging the two models.

(4) The capstone experience supports a dynamic range of student growth.

Learning research that fits within Rogoff's Multiple Planes of Development model may benefit from this integration with Fuller's Stages of Concern model, especially when exploring complex data sets and complex concepts such as professional identity formation.

Chapter 5

Discussion and Conclusions

5.1 Recapitulation

Professional Identity (PI) formation may be sustained through exposure to and use of professional practices in an educational setting, as with a CS capstone course. The CS capstone under scrutiny puts students into collaborative teams with an external sponsor, working to apply software engineering practices toward solution development and implementation. The course is situated at the juncture between academia and industry, with seniors in a CS major prior to their transition into the workplace.

In order to facilitate deeper exploration of this potential influence, my dissertation studies gathered student reflections on their project experiences. The form of these reflections included interviews and class artifacts from individuals and teams.

The series of three papers, as chapter 2 [66], chapter 3 [68], and chapter 4 [70], presented my publications during this research study. Here is a summary of each chapter and the associated research questions.

5.1.1 RQ1: Role of Emotions

RQ1: What role does emotion play in influencing engagement and professional identity formation in a CS capstone course? In chapter 2, "How Do You Feel" [66] explored the role of affective expressions from student interviews at the conclusion of their CS capstone experience. Findings focused on the sponsor's role during project selection and evaluation; the

span of emotions across positive and negative valence, as well as confidence and uncertainty; and the variations in experience depicting an "emotional rollercoaster" [19].

In CS Education, emotions may be overlooked as a supporting factor of student experience [34], despite evidence that education spans cognitive (thinking), affective (feeling), and psychomotor (doing) domains [3]. Drawing from thematic analysis of end-of-project student interviews, my study examined sponsors as role models, students engaging in the authentic labor of their projects, and the journey of a project from start to end. These points offer insight into the role that a focus on emotions plays for student engagement and PI formation. The findings provide evidence that CS Capstone projects are a fertile space for investigating emotions in CS [66].

As a building block, RQ1 directly explores breadth of student affective expressions in their interviews and its link to their sense of authentic engagement and legitimate project ownership. The *confidence and uncertainty* thematic work mirrors early outcomes from Fuller's Stages of Concern development [36]. Of particular interest are my findings that students discuss their sense of confidence and concern interwoven with both positive and negative affect.

A similar finding in the study is that all participants cited project strengths and weaknesses. These included how they would change the project practices if they were hypothetically moving forward, alongside what they would retain of practices. Researchers of a Masters capstone reviewed evidence of failed transfer, where student teams did not incorporate best practices into their project work [4]. My study found student discussions about which practices they might integrate, as well as which practices they would continue using or not using. I claim this represents greater professional maturity and readiness to engage actively in dialog about how to adapt and apply best practices given specific project needs. In other words, at the conclusion of their projects, CS capstone students engage in discourse about outcome-oriented application and withholding of best practices. This evidence of professional maturity directly indicates strengthened PI formation as an outcome of the CS capstone course.

5.1.2   RQ2: Role of Interest

RQ2: How does using student interest as the primary basis for forming teams influence student experience in their capstone project? Chapter 3, "Interest-based Capstone Team Formation" [68] examined the influence of interest-based CS capstone teams on student experiences. Student interviews explored the role of legitimate, real-world projects; engagement of students in pursuit of project-relevant outcomes; and ownership of the project, in the form of making and defending design decisions.

Margolis and Fisher explored *interest* and *confidence* as interrelated concepts contributing to student decisions to stay or withdraw from CS [55]. In running CS capstone projects, the course structure of gathering informed project preferences from students impacts the class experience. Teams founded on a shared interest around seeing a project succeed are able to leverage that common foundation in response to myriad challenges that arise as part of a real-world project.

By drawing evidence of student perceptions about their CS capstone experience from early and end-of-project interviews, my study focused on the influence of *interest* as a launching point of a collaborative project. Revisiting this study through the lens of Stages of Concern, CS capstone teams are formed based on shared interest in the sponsor's vision of potential project outcomes. From the launch of each capstone project, then, students have a foundation available for building their collaboration upon, one which encourages progression of their concerns to the *outcome* stage. Throughout the project, as challenges and obstacles arise and must be addressed, the team (encouraged by their team advisor) has this shared outcome-oriented interest pulling them to focus on real-world impact and user needs.

It is significant that CS capstones couple this foundation with a longer duration for the team to remain engaged with professional roles and practices, as PI formation requires more time for identity change to set in [13]. I claim that the course practice of using interest to drive team formation contributes to student engagement and project ownership, and sustains PI formation by offering an outcome-oriented foundation for the project to build on.

Student interviews included personal reflections on the transition from an academic to a professional mindset:

> Definitely the latter half of the year was more focused on our sponsor. Our sponsor getting more involved. He was asking more questions, really challenging more of our ideas, and at that point I really felt, 'okay, this is a project for the sponsor.' No longer was it, you know, 'I need to make this grade in this class for my professor,' it was, 'I need to satisfy my sponsor, I need to make sure he's happy.' So it definitely shifted halfway through. – *[Thomas, 2014-15, End of project Interview]*

5.1.3   RQ3: Multiple Planes of Concern

RQ3: What is the interplay between planes of development and stages of concern as underpinning professional identity formation? Chapter 4 introduced my proposed model, Multiple Planes of Concern (MPoC), with a case study drawing from individual and group artifacts of the CS capstone course [70]. MPoC extends Rogoff's Multiple Planes of Development analytical model [49, 78, 79] with Fuller's Teacher Concerns Model [38]. Planes of Development is a sociocultural model for examining evidence of changing practices, while the Teacher Concerns Model offers structure for reviewing evidence of maturing professional identity. By combining the two models, the resulting MPoC model offers a method for analyzing PI formation evidence through changing participation-based concerns. Analysis of class artifacts from the CS capstone course offer an example application of MPoC as modeling an individual progressing across stages within each plane, as well as two teams with differing evidence of staged progressing within the planes.

Rogoff and other sociocultural learning theorists leverage Multiple Planes of Development for investigating any learning, offering flexibility and extensibility as appropriate for specific research project needs [79]. Fuller's work with concerns has been integrated into the Concerns-Based Adoption Model (CBAM) as Stages of Concern, and represents an assessment of individual attitudes, beliefs, and identity [44]. In MPoC, my dual dimensions for analysis of development and concern come together in a framework for investigating *Situated Identity*. Situated Identity places PI formation at the center of the analysis of development. This is in contrast to situated learning and related theories that relegate identity to a co-occurring byproduct of the changing practices [53].

RQ3 (chapter 4) lays out the MPoC model and demonstrates its usage through analysis of student teams. The case study included two main threads, one focused on the individual and the other on teams.

Marie's story is significant because it spans most of the concern stages across all three developmental planes. The evidence from personal goals and peer evaluations suggests early struggles she experienced with doubt (personal plane) and inability to engage with her peers (interpersonal plane) in professional software development practices (community of practice plane). The mid-project personal goals assignment captured Marie's turning point decision to engage by taking ownership of a feature of the project, shifting from self-oriented concerns toward task-oriented ones. End of project evaluations and reflections offer evidence of the further progression she experienced, including the maturing of her confidence such that she accepted employment to continue as primary developer of the project. Marie epitomizes the potential role of CS capstone for progress of PI formation accompanying changing practices.

The different experiences of teams Beta and Gamma highlights the dichotomy between a team that together drove the project with focus on sponsor needs and outcomes (Beta) and a team that appeared to check the boxes but required significant prompting to satisfy the tasks of the project (Gamma). This dual story brings to the forefront the breadth of student experiences emerging from the CS capstone, demonstrating the range of application possible with the MPoC model. For my overarching research question, however, it is more important to note that some individuals and teams will complete the CS capstone experience without reaching a fully mature PI.

5.2   Outcomes

My dissertation research offers several novel contributions across theory, CS capstone implementation, PI formation, as well as the produced CS Capstone Dataset and a policy model whereby I gathered informed consent for use of academic artifacts. In this section, I review each outcome, including evidence and my interpretation of significance.

Table 5.1: Review of the structure for the Multiple Planes of Concern model.

		Stages of Concerns		
		Self	Task	Outcome
Development Planes	Personal	What is my role? Am I adequate?	Is what I am doing working right?	Is what I am doing meeting a need?
	Interpersonal	Am I an adequate team member? Can I trust my team?	Is our team working right?	Is what our team is doing meeting a need?
	Community	What is my future role? Am I an adequate software engineer?	Am I doing software engineering right?	Am I meeting a need with my software engineering role?

5.2.1 Outcome 1: Theoretical Model

The theoretical model I proposed, Multiple Planes of Concern (MPoC), is summarized in table 5.1. It is a novel method for structuring evidence of identity maturity from Fuller's Teacher Concerns Model [38] into Rogoff's Multiple Planes of Development [78]. Sociocultural learning models, such as Situated Learning and Communities of Practice, acknowledge *identity* as forming alongside changing practices as individuals progress along a trajectory of participation. My extension with the concerns model supports explicitly studying the PI formation process that occurs with changing practices.

MPoC offers a structured method for exploring PI formation through confidence and concerns that accompany changing practices. I have applied the model to students working in a CS capstone course. Next steps may include data gathered across the university-to-work transition, from first year projects through to early career professionals in CS. Alternatively, MPoC offers benefit to other investigations of developing PI, as in Engineering Identity research at the university/work boundary. PI is leveraged as a concept in the established professions of medicine [64], law [94], and health sciences [25]. These disciplines may also benefit from MPoC as a method for analyzing

student artifacts and self-reflections.

My development of MPoC is a model for PI formation as evidenced by stages of concern accompanying developing professional practices. MPoC grew out of the analytical and exploratory work of investigating PI formation as influenced by my observations of maturing confidence in CS capstone students. With RQ1 (chapter 2), thematic analysis centered around the two axes of valence (positive, neutral, negative) and confidence (confident, neutral, uncertain). The confidence spectrum is a preliminary form of my use of Stages of Concern. With RQ2 (chapter 3), the role of interest-driven team assignments creates a shared foundation around the potential project outcomes. This structuring of the CS capstone contributes to an experience where student teams may find an easier transition to outcome-oriented concerns across all three planes of development.

The CS capstone supports PI formation, yet in its current instantiation at this institution, there are diverse outcomes experienced by students and teams. Use of MPoC may distinguish factors that contribute to greater or diminished development across planes of concern, informing future adaptation of the course structure.

From Situated Learning, a key insight bridging Rogoff's and Fuller's models is the role of current practices in supporting future participation [53, 78, 91]. As an example of this bridging in action with the CS capstone, one student reflected: "A lot of the problems that I tackle now [after graduation], I tackle it in a way that I learned from the [capstone] project" – [Eric, 2014-15, end of project interview].

Another quote further distinguishes the CS capstone from other CS coursework: "It's one of those things where I know there's been various projects that I've worked on where I'm just trying to cram it out and get a grade. In this case [CS capstone project], I want it to be something that I am proud of" – [Lucas, 2015-16, early project interview].

Students may not naturally strive to integrate professional practices into their projects [4], hence the creation of a space for cultural encounter and experiencing the profession while still in a familiar educational setting [8]. In addition to encouraging teams to own their projects, the CS capstone structure intervenes with strategies and mentorship on how to be effective communicators

[57] and address potential interpersonal conflicts effectively through bystander training [22]. Thus my claim that CS capstone is a situated identity intervention, assisting many students to progress beyond *self*-oriented concerns, and grounding their capacity for engaging in cultural discourse as they move forward with their careers.

5.2.2   Outcome 2: Learning about CS Capstone

The CS capstone course in software engineering as studied in this dissertation runs for a full academic year, with seniors on teams of four to six students. Each team works with an external sponsor to develop a software solution. The software engineering projects are selected by 90-95% of Bachelors of Science students in the CS major, so that "the [CS] department relies heavily on student achievement in [the CS capstone] course as a measure of how well the [BSCS] program is meeting its [ABET] outcomes" [26].

From a survey of CS capstone literature, most capstones include "a final year, [one or two] semester long, group based, software engineering project" [28]. Many variations exist across the nation [28]. Similarly, each capstone team engages with its own project, introducing even more variation into the details around the capstone experience. A study that relies on Rogoff's planes of development theory explains their approach as "supporting and responding to the 'messiness' of real life social and cultural complexity and diversity" [49]. The many variants involved with running the portfolio of CS capstone projects each academic year is a "messy" learning space, yet it is also a meaningful experience for students.

From FCQ data gathered at the conclusion of each semester, students are asked to respond to the statement, *This course prepared me for my chosen career* on a six-point Likert-scale from *strongly agree* to *strongly disagree*. From Fall 2013 through Spring 2017, 80.6% of responders indicated some level of agreement (43.7% strongly agree, 23.1% agree, 13.9% somewhat agree). A plot of responses to this question appears in figure 5.1. In addition, observations and anecdotal evidence supported the claim that *something significant* is changing in students during the CS capstone experience. An example from a sponsor evaluation at the conclusion of the project: "The

FCQ Question B94:
This course prepared me for my chosen career.
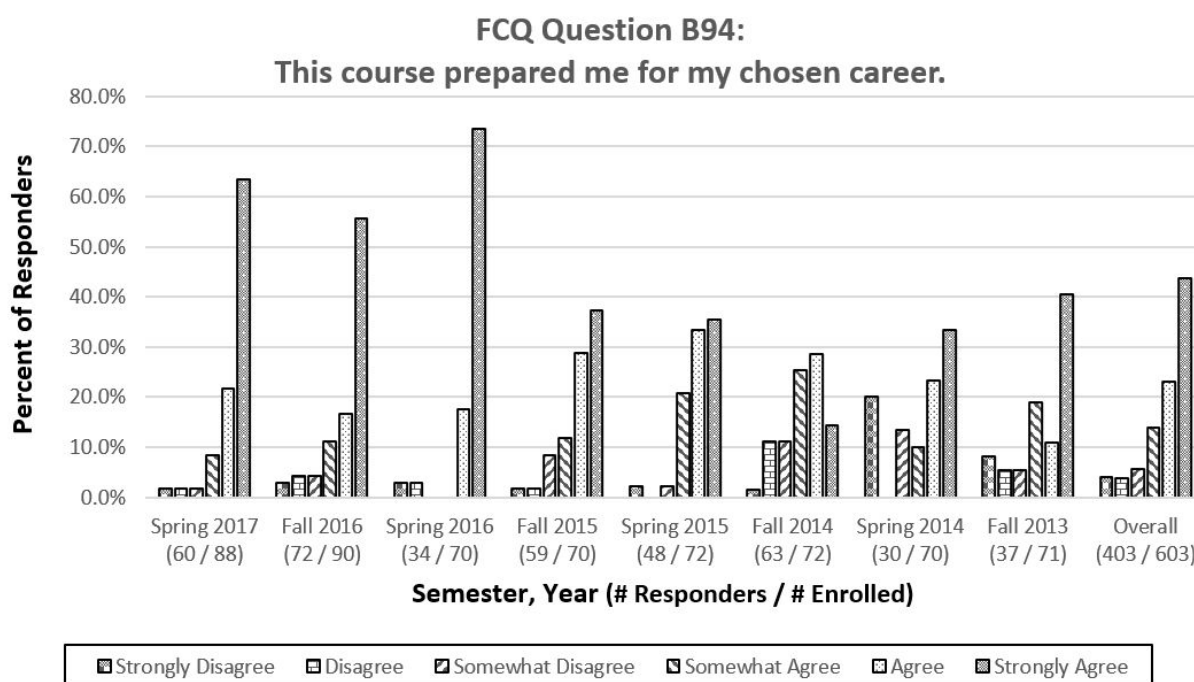
Figure 5.1: Response rates for end-of-semester course questionnaires from 2013-14 AY to 2016-17 AY about how course has prepared students for their chosen career.

person they were at the beginning [of the CS capstone project] to who they are now are almost incomparable. They are not the same students that they were when we first met. – *[Team Beta, End of Spring Sponsor Evaluation]*" My studies push beyond the end-of-class survey to identify what about the CS capstone experience contributes to the positive response from students.

Prior to this dissertation research, no work existed to map the course structure to learning outcomes beyond FCQ data and evidence gathered to demonstrate ABET outcomes [26]. "Given the volume of literature about computer science capstone courses, it was surprising that so little work was based on formal learning theory" [28]. A significant contribution of this dissertation research is the exploration of connections between learning theory and the course structure. To portray these connections, I use conjecture mapping from the learning sciences [81].

Conjecture mapping is a helpful method for considering design of formal and informal learning experiences, as it supports simultaneous development of learning theory alongside iterating on the structure of the learning experience [81]. My proposed conjecture map connects how I now

understand learning as occurring in the CS capstone experience and the evidence gathered through student interviews and course artifacts of said learning.

5.2.2.1   Conjecture Map for CS Capstone

Conjecture mapping draws from design research methods in the learning sciences [81]. The use of conjecture maps supports discussion around how conjectures about learning are embedded into both formal and informal learning contexts [81]. Figure 5.2 presents my conjecture map for the CS capstone course as a method for reviewing the course-specific findings from this dissertation research. The mapping process invites educational designers to consider what learners will do in the learning context, and what learning outcomes may arise from those activities [81]. Conjecture maps support iteration on course design [81], although I use it primarily to capture the results of this dissertation research. In some respects, the conjecture map serves as an input into the next series of iterations for continued study and development of the CS capstone course.

One definition of PI formation "is about connecting with roles, responsibilities, values, and ethical standards unique to a specific profession" [41]. My overarching research question, **what is the influence of a CS capstone course on undergraduate development of PI during the university-to-work transition?**, parallels my overarching conjecture. Namely, that the CS capstone course has capacity to support PI formation for CS undergraduate students.

5.2.2.2   Embodiment

Conjecture mapping suggests its own lens for analyzing how learning theories are embodied in the learning space, namely through *participant roles and structures*, *tools and materials*, *task structures*, and *discourse* [81]. These all represent salient design features of the learning experience which should give opportunities for students to act through *mediating processes* in the learning space, and that by their actions, they may achieve intervention outcomes [81].

Using these categories to organize features of the CS capstone embodiment of learning design would yield the following outline:

From Theory to Design

Design Conjectures

Theoretical Conjectures

Embodiment:
(translating high-level conjecture into design features)

Mediating Processes:
(processes occurring during enactment)

Intervention Outcomes:
(how processes affect learning)

High-Level Conjectures:
(Claims derived from learning theory)

Affect (emotional response) plays a significant role for students in the CS Senior Project experience

Interest-based team formation supports team engagement and collaboration

CS Senior Projects transition students toward professionalism, collaboration and team trust

Participant Roles & Structures
- Sponsored projects pitched at Sponsor Fair
- Self-directed Teams

Discourse
- Communication Styles intervention
- Peer Evaluation Process

Task Structure
- Long project timetable
- Interest-based Teams
- Unknown project outcomes and solutions

Tools & Materials
- Safety net of university setting, sponsor support
- Practices of Software

Students work directly with sponsor, users, Subject Matter Experts, faculty, project mentors

Students struggle through authentic solution process of applying Software Engineering Practices

Students engage strategies for communication and interpersonal/team dynamics

Students take ownership of their project decisions:
- Make decisions
- Defend decisions
- Follow through on decisions

Confidence in professional craft Academic to Professional mindset growth/ augmentation

Confidence improves in doing CS practices Mastery (why's behind the practices)

Future careers/roles
- Appreciation of
- Claiming/owning

Deeper appreciation of relevance of CS to society

Collaborating capacity expands

Figure 5.2: Conjecture mapping of claims about CS capstone course.

(1) Participant Roles and Structures

    (a) Sponsored projects

    (b) Projects pitched in-person at Sponsor Fair

    (c) Self-directed and self-organized teams

    (d) Every team member owns a project role

(2) Tools and Materials

    (a) Safety net: university setting, sponsor support

    (b) Practices and methods of software engineering

    (c) Team decides how to adapt practices for project needs

(3) Task Structures

    (a) Long project timetable

    (b) Interest-based teams

    (c) Unknown project outcomes and solutions

(4) Discourse

    (a) Communication Styles intervention

    (b) Peer evaluation process

    (c) "War Stories" from authentic practices (successful and challenged)

5.2.2.3   Mediating Processes

While the course embodiment features are only highlights from all aspects of the course structure, these are meaningful in that they may contribute toward student engagement with specific practices - the 'what' that students do in mediating their learning. The extent to which students

actually engage with these mediating processes can be observed and measured, with alterations to the embodiment guided toward improving that engagement.

Mediating processes that are significant for the CS capstone course include:

(1) Students work directly with:

    (a) Project sponsors

    (b) Users

    (c) Subject Matter Experts

    (d) Faculty

    (e) Project team members

(2) Students struggle through authentic solution process of applying Software Engineering Practices

(3) Students engage strategies for communication and interpersonal/team dynamics

(4) Students take ownership of their project decisions

    (a) Student teams make project decisions

    (b) Student teams defend project decisions

    (c) Student teams follow-through on project decisions

Design conjectures are the linkage between embodiment and mediating processes, and can be verified through observation of students in the learning space. For example, with the dashed lines in figure 5.2 between the embodiment column and the mediating processes column: a design conjecture is that students will take ownership (make, defend, and follow-through) on project decisions, because of the embodiment of having self-directed teams, long project timetable, unknown project outcomes and solutions, and use of the practices of software engineering. In a space with an unknown solution, the team has opportunity to "try something first" in moving the project forward

into the unknown. With a long project timetable, they will see the outcomes of those decisions, with time to revisit and make changes.

The act of observing lends itself to checking whether and how much teams actually are taking ownership of the project decisions. If some teams are more readily engaging with owning their projects and others are not, this observation serves as feedback for iterating on what differentiates the two teams and how the course embodiment might be altered to drive the desired mediating process more effectively.

5.2.2.4   Intervention Outcomes

The step from mediating process to outcomes is the link between what students are doing in the learning space and what the expected result should be. As with checking whether students are actually engaging with the mediating processes, similar verification of intervention outcomes offers confirmation that learning is occurring as hypothesized. When the outcome is not verified, deeper investigation is appropriate to identify where the breakdown may be occurring and how to address it.

Intervention outcomes that I focus on at this stage of investigating CS capstones are:

(1) Confidence in the professional craft of software engineering

(2) Academic to professional mindset growth or acquisition

(3) Confidence improves in doing CS practices

(4) Mastery (the 'why' behind the professional practice)

(5) Future careers and roles

    (a) Appreciation of

    (b) Claiming and owning

(6) Deeper appreciation of the relevance of CS to society

(7) Collaborating capacity expands

An example linking student actions from the mediating processes to intervention outcomes, represented by dashed lines from mediating processes to intervention outcomes in figure 5.2, might look like the hypothesis that students' sense of ownership over their project contributes to building their confidence about their professional craft, alongside their confidence to engage with those practices with an understanding of the 'why' behind the practices.

A challenge in laying out a conjecture map is that multiple factors contribute from one layer of the map to the next. While my dissertation research contributes to laying out a first iteration of a conjecture map, continued study of these conjectured links may refute or support the map. Within those findings, then, the embodiment of the course as well as the overarching conjectures will be open for refining and improving.

5.2.2.5   Practices to Consider Changing

My new model for sustaining PI formation, Multiple Planes of Concern (MPoC), integrates progressing stages of confidence and concerns across the developmental planes of personal, interpersonal, and community. With this framing of the support for PI formation, the following suggestions may be beneficial for upcoming iterations of the CS capstone course implementation.

In terms of discourse, informally, I have noted that there may be a transition of language used by student teams somewhere between the first and second technical presentations. With the first presentation, teams often refer to "our *sponsor's* problem," with other language to indicate that they are still figuring out how to connect with and understand the work the sponsor has brought to the project. By the second (or for some, third) presentation, teams talk about "*our* project is to do ...," a verbal cue that the team is taking greater ownership of their experience. There may be opportunity for capturing this transition more rigorously.

Team Identity through T-Shirts: To contribute to stronger development of the interpersonal plane, there may be opportunities for supporting teams in creating and owning a team identity. Each year, with the project kick-off presentation, teams are invited to create a team name and

other aspects of a team identity. Most teams decide on a team identifier, though some teams refer to their project as the sponsor's organization. In AY 2015-16, one team decided that they wanted to design and purchase team t-shirts. This may be a meaningful practice for teams to engage in.

In AY 2017-18, as instructor for the course, I invited all teams to design team t-shirts, and the course procured them. A restriction imposed by the procurement process was that team shirts could not include any logos or references to the university, the CS department, or to the sponsor. Shirt design occurred midway through the second semester of the projects. About half of the teams participated, while the rest skipped the opportunity.

Based on the potential for greater team identity formation in support of interpersonal development, the cohort of teams for AY 2018-19 was invited to design team t-shirts with their own logo and team name between the first and second presentations. All teams but one chose to participate in this design project.

This timing aligns with the hypothesized shift in discourse occurring as teams take ownership of the project. Inspection of individual and team artifacts may support or counter the hypothesis of this practice influencing team identity formation, especially as compared against team identity formation from previous years.

The use of team t-shirts is an example of a practice that may coincide with a developmental plane. The proposed structure of MPoC will similarly suggest additional opportunities for modifying the course embodiment in support of PI formation outcomes.

5.2.3   Outcome 3: Broader Implications

The core set of papers produced in this dissertation indicate support for the PI formation process in educational spaces, especially focused around CS. The first paper (chapter 2) calls out the importance of student emotional experiences and acknowledging that side of the challenging work of forming PI. As one research team asked, "is there energy within the [CS] departments to make room for people who want strong bonds with people?" [9].

An established researcher in Engineering Identity [40] discussed limitations her research group

encountered in attempting to adapt survey items for Engineering Identity to the CS discipline [39]. Some of my preliminary work [69] explores adaptation of a core Engineering Identity instrument, transitioning from the question, "Do you feel you are becoming an engineer?" [58] to a broader exploration of future professional CS roles.

In addition to a possible path forward with a CS PI instrument, my work suggests the importance of supporting PI formation within the university and across the university-to-work transition. My concerns-based model of PI formation, MPoC, offers a structured approach for meeting students where they are at, with the concerns they are actively facing.

5.2.4   Outcome 4: Dataset

The CS Capstone Dataset, comprising the combined data sources listed in tables 1.3 (individual data sources) and 1.4 (team data sources), represents its own contribution as a novel collection of rich student interview data, class artifacts from individuals and teams, and survey responses including reflections on CS capstone influence after graduation.

Prior to the work of this dissertation to gather and analyze the dataset, the state of practice in assessing the influence of the CS capstone course was the CS department's reliance on course questionnaires (FCQs) at the end of each semester, combined with input from the department advisory board [26]. Development of the CS Capstone Dataset integrates student perspectives on their experience through individual interviews and follow-up alumni surveys. These personal reflections from students and alumni are supplemented by the academic artifacts, now formally approved for integration into research and publications.

This CS Capstone Dataset is available to the public through the Open Science Framework (OSF) at [67]. By making the dataset available for other researchers, continued exploration of the influence of the CS capstone course may be pursued. Some questions not yet explored include:

(1) Does the CS capstone influence on PI formation differ for men and women?

(2) As part of team dynamics, each student completed a communication styles assessment [57].

How does CS capstone influence vary for different communication styles?

(3) How does project experience differ with team size (four, five, or six students)? Is there an ideal team size?

(4) Are there different learning outcomes with project sponsors drawn from industry or academia?

In addition, publishing the gathered dataset serves as an invitation for greater collaboration and further development of data collection across other researchers and research institutions.

5.2.5   Outcome 5: Policy Model

A helpful innovation offered in my dissertation research is the development of a policy model for gathering student consent for academic work to be included in a research study. Prior to my work, academic artifacts from conducting courses in the university educational setting could be used for grading purposes and for internal improvement of the course by the instructor of record. Specific assignments were tracked and reported in the CS department's internal and confidential self-study report for ABET review, for example [26]. However, external publications, such as at conferences and in research journals, could not integrate analysis of class artifacts without gathering student consent in some form.

In coordination with the CS capstone course and IRB, I crafted an acceptable method for outreach and consent for use of university academic artifacts in my dissertation research. The end result was that I obtained permission from many of the current and former students for integrating their individual and team class artifacts from the CS capstone experience into my research.

A challenge driving my approach for the consent policy was that four cohorts of CS capstone students had already completed the course. Most individuals were no longer at the university or actively checking their university-issued email, which previously had been the primary avenue for communication outside of class. An opportunity I considered in forming the policy was that the fifth cohort was actively enrolled in the course, prompting development of a method for in-person consent gathering.

One strong recommendation from the IRB was for the consent process to be established independent of the course syllabus [42]. As a result, the process of obtaining consent could be applied and adapted without directly integrating IRB review of course design and planning updates. Further, "[i]ncluding this research information [in the course syllabus] may inadvertently cause students to construe participation as a course requirement which would not be correct" [42].

My approach for gathering consent is two-pronged, namely contacting students/alumni in person and via internet/social media. I developed two versions of recruiting material, one with a digital consent script (see Appendix B) and the other a template for verbal interactions, which invited participants to complete the online consent survey. The consent process included a method for granting consent, as well as for revoking consent or limiting specific materials approved for research use.

Internet/social media outreach used the email addresses issued by the university when students were enrolled, as well as my personal LinkedIn connections to many former students and the CS department's alumni LinkedIn group. For both internet and in-person consent, a "snowball" recruiting step was included, whereby respondents are invited to assist me in contacting their team members [27]. All of the outreach material included instructions for contacting the research team should any student decide to revoke or limit their consent.

A key factor in implementing the consent policy for in-person recruiting was requesting consent independent of and prior to actually having access to the class artifacts for research work. In essence, none of the material that has been consented to be used for research will be integrated into the research dataset until two weeks after final grades are posted at the conclusion of that academic year. This approach encourages students to consider the research review of their work as occurring in a manner that cannot have repercussions on the grade outcome of their project work.

5.2.5.1   Types of Artifacts Linked to Consent Requirements

In establishing the consent policy, a key factor was differentiating what consent is needed and from whom. The policy I adopted is that students must grant consent for academic work that

they submitted as part of their class experience. The implications of this approach are fourfold.

First, individual work submitted for grading during the course require consent from the individual student. This step is straightforward and follows naturally from individual-based assignments as occur in many courses.

Second, team assignments submitted for grading during the course require consent from all team members. Often, one submission would be provided by a single team member representing contributions of the entire team. By requiring consent granted by all team members, any one team member can refuse, removing all of that team's group artifacts from my research. Furthermore, lack of response from any team member also prevents use of the team artifacts.

Third, my policy includes defining artifacts that do not require consent. I explicitly differentiate student submissions of work from the evaluations of that work, especially external evaluations as are received from project sponsors. For peer evaluations of projects, students must consent for their individual evaluation submission, but the resulting evaluation of team effort is not constrained by the team.

Fourth, any artifacts generated by the team for public distribution do not require consent for review. Public forums related to the CS capstone experience include the public project exposition and related posters and handouts, as well as the team presentations throughout the course. Part of the mentoring of teams during the course includes reminders to keep confidential or proprietary information out of the presentations and posters. This is in keeping with these artifacts as open for external distribution and review, including research use. In a similar way, any teams who were approved by their project sponsor to store their project source code repository on a public Github forum

5.2.5.2   Outcomes of Consent Policy

Individual response rates for consenting to participation in this research project are indicated in table 1.3. As anticipated with use of university-issued email addresses, response rate was lower for each successively earlier cohort of students. The highest response rate (96%) was attained from

in-person recruiting for the current cohort of students.

LinkedIn connections represent an indication from alumni of willingness to maintain a professional connection. During the outreach process, two of the 395 individuals in the research population directly responded to indicate that they were not interested in participation or in further communication about research (0.5%). Two separate respondents (0.5%) indicated that they were willing to have their team data included in the research work, but asked for their individual assignments to be excluded.

Three respondents (0.8%) indicated that they would prefer not to be included in the research, but were open to discussing further. Through additional exchanges, each of these three expressed specific concerns about the research that they felt had not been adequately addressed. After offering additional detail about the research work and its purposes, each consented to having their work included. One of these indicated he just didn't feel confident he recalled enough about his academic work four years after the fact to know what he was consenting to. Before adding his academic work to the research dataset, I forwarded the collection of artifacts to him directly. I included markers for the deidentification process to demonstrate what would be removed, offering visibility of the end state of his data. After having opportunity to revisit his prior work, he indicated he consented to having his data included in the research.

As a byproduct of gathering consent for both individual classwork and teamwork, if any individual did not provide consent or failed to respond at all, I considered the teamwork as not approved for inclusion in this research work. Of the 72 projects in the focus five years of this research project, 26 teams had every team member respond to my recruiting efforts with their full consent for their teamwork to be included (36%).

5.3   Core RQ: Influence of CS Capstone

Overarching the other research questions is this core one: **RQ: What is the influence of a CS capstone course on undergraduate development of professional identity during the university-to-work transition?** Many students completing the CS capstone indicated on

their course feedback survey (FCQs) that the experience was meaningful in preparing for a future role in the computing profession. This dissertation research advanced theory at the intersection of learning science and CS PI formation, with concrete recommendations for implementing a CS Capstone in software engineering, and insights for supporting PI formation in broader academic settings. This work delves deeper into the PI formation underpinning the high level FCQ feedback, exploring specific ways the course structure contributed to the university-to-work transition for many students. The developed dataset sustains this and future investigations into CS PI formation, as does the model of my academic consent policy.

5.4   Limitations of Research

My dissertation research is exploratory in nature, as represented in the research questions pursued. As such, my proposed method, Multiple Planes of Concern (MPoC), offers a possible approach for organizing interview data and reflective course artifacts around planes of development and stages of concern. Within the scope of exploration, the applicability of the model as supporting exploring what is meaningful for students in reflecting on their CS capstone experience is demonstrated. However, this work does not speak to questions of how prevalent given themes or stages of concern may be across various demographics. Work to explore quantitative aspects of these same constructs might include exploring how prevalent given stages of concern are within the CS capstone experience or at different time intervals across the course.

In terms of validity of results, my proposed model highlights salient themes identified from thematic analysis [11]. To perform thematic analysis, I was supported by undergraduate research assistants and by my advisor's reading group. With the exploration phase of my research, this approach is very appropriate, as discussion of the identified themes was performed by human contributors thinking over how transcribed dialog represents different topics of importance. When transitioning to a subsequent stage of research, the structure of MPoC will be adapted into a coding dictionary, with example and counterexample statements from previous interview data. Given a specific segment of interview data, I can then train a group of readers on each stage of concern

across the developmental planes. The trained readers would then code the training segment, and could perform coding of a set of reflective data. The results of this calibrated coding process would support computing inter-rater reliability (IRR), offering feedback on which parts of MPoC are consistently applied well and which cause confusion or division in coder usage.

Capturing IRR thus represents a viable next step for validating the MPoC structure and its potential for consistent use by researchers. The outcomes of this dissertation research provide significant foundational support for determining how consistently various raters might be when applying MPoC.

The naturalistic inquiry approach [54] gathers interviews from course participants about their perceptions of what is meaningful from their experience, and then explores across the various participants for patterns and themes [11]. Other researchers in the CS education space have similarly found success with this approach [55], despite working primarily with a single institution or course. Additional insights are possible by broader data collection, to include additional institution types, locations, and demographics of the populations served.

It is important to note that my findings are specific to the CS capstone course under investigation at a single R1 research institution in the Midwestern United States. Other types of professionalizing experiences may show similar findings about the role of professional experience in supporting PI formation for learners. These may include coding bootcamps, independent study projects, internships, and the practice of first-year projects as implemented at some companies.

At this point, my data gathering has focused primarily on participants in the CS capstone course, and artifacts from their enrollment in the course. I have limited longitudinal data from the follow-on survey for gathering consent to use academic artifacts, as I included the question, "How has your senior project influenced your career (positively and negatively)?" Deeper exploration, possibly to include follow-on interviews, may assist in generating greater longitudinal data about participant experience beyond the course under investigation.

5.5   Future Work

In my dissertation studies, I gathered and analyzed student interviews, alongside reflective individual and team assignments, resulting in my proposed MPoC model for investigating *Situated Identity*. Moving forward, this model will benefit from additional data gathering across the university-to-work transition, from first year projects through to early career professionals in CS. What educational experiences arouse specific stages of concerns? How are these staged concerns expressed across varying demographics, including gender, race, culture, and intersections across these categorizations?

Thinking beyond CS, how does the MPoC model transfer across to other professions? The model may benefit investigations of developing PI in other professions, as with Engineering Identity research work at the university/work boundary. PI is leveraged as a concept in the established professions of medicine, law, and health sciences. In addition to benefiting these disciplines by integrating MPoC as a method for analyzing student artifacts and self-reflections, there may be opportunity for examining how disciplinary differences influence development of concerns.

Another method for future development is transitioning MPoC from an open-ended qualitative instrument to a quantitative survey instrument on concerns. Fuller's Teacher Concerns Model underwent a similar progression, as researchers were able to identify recurring concerns across varying stages of professional development for educators. The result was a divide between Teacher Concerns Statement (TCS, qualitative) and the Teacher Concerns Checklist (TCCL, quantitative) [73]. The two instruments offered different insights, similar to checking recall against recognition in advertising [45]. A comparable benefit may be achievable once CS PI formation concerns are more fully mapped out.

A broader question arising from my dissertation research is the capacity for engagement of graduates from the CS capstone experience. Limitations of engagement may be demonstrated through struggles to find or maintain a job, or by the decision to change careers away from CS disciplines. Looking to the successful end of engaged graduates, Situated Learning suggests that

these individuals may better integrate into the professional community of practice, and through that integration, may be in a stronger position for engaging in discourse around shaping the culture and practices of that professional community [53, 95]. A significant factor in this transition is whether the new entrants into the community are accepted as authentic practitioners, which may correlate with maturity of PI formation [53]. Are graduates with mature PI more confident and better accepted when attempting to engage in dialog about professional practices after graduation? Do interventions (such as the CS capstone) help create resilient graduates who are capable of such engagement?

5.6   Conclusions

I advanced theory at the intersection of learning sciences and formation of PI in CS. I reported concrete findings about the CS capstone implementation, including recommendations for features to keep and to consider altering. I offer broader implications, both for supporting CS PI across the CS curriculum and for supporting PI beyond CS.

Attrition is a concern in CS, yet may not be high on the list of concerns for all faculty who are creating and teaching CS courses. Many institutions across the nation are struggling to address a significant surge in enrollment [15]. Research into previous CS enrollment surges and how they are addressed indicates that even the response to "more students to teach" can impact the distribution of which students stay and who withdraws [63]. Furthermore, "most of us teach what we were taught and teach it in the way that we were taught it" [72]. Where resources are already stretched thin to address those students who "get it", many of the ones who struggle with early stages of self-oriented concerns will fall by the wayside.

Improving support for forming CS PI will improve retention and reduce attrition rates, or referring back to the parable of the travelers, it will encourage more travelers to struggle along the professional path despite barriers and obstacles. Beyond this, the CS discipline needs travelers capable of improving the path they are on, and who build bridges and pursue opportunities far beyond what is currently achievable. "Great design comes from great designers. Software con-

struction is a *creative* process. Sound methodology can empower and liberate the creative mind; it cannot enflame or inspire the drudge.... The most important single effort we can mount is to develop ways to grow great designers" [12, emphasis in original]. Through my dissertation research, I study the development of software engineers and the influence of CS PI formation sustained by practical experience.

Bibliography

[1] Mahmoud Abdulwahed and Zoltan K. Nagy. Applying Kolb's experiential learning cycle for laboratory education. Journal of Engineering Education, 98(3):283–294, 2009.

[2] Edith Ackermann. Piaget's constructivism, Papert's constructionism: What's the difference. Future of Learning Group Publication, 5(3):438, 2001.

[3] Lorin W. Anderson, David R. Krathwohl, Peter W. Airasian, Kathleen A. Cruikshank, Richard E. Mayer, Paul R. Pintrich, James Raths, and Merlin C. Wittrock. A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives. White Plains, NY: Longman, 2001.

[4] Ray Bareiss and Edward Katz. An exploration of knowledge and skills transfer from a formal software engineering curriculum to a capstone practicum project. In 2011 24th IEEE-CS Conference on Software Engineering Education and Training (CSEE&T), pages 71–80. IEEE, 2011.

[5] Andrew Begel and Beth Simon. Novice software developers, all over again. In Proceeding of the Fourth International Workshop on Computing Education Research, pages 3–14, 2008.

[6] Andrew Begel and Beth Simon. Struggles of new college graduates in their first software development job. In ACM SIGCSE Bulletin, volume 40, pages 226–230. ACM, 2008.

[7] Mordechai Ben-Ari. Situated learning in computer science education. Computer Science Education, 14(2):85–100, 2004.

[8] Yifat Ben-David Kolikant and Mordechai Ben-Ari. Fertile zones of cultural encounter in computer science education. The Journal of the Learning Sciences, 17(1):1–32, 2008.

[9] Maureen Biggers, Anne Brauer, and Tuba Yilmaz. Student perceptions of computer science: A retention study comparing graduating seniors with CS leavers. SIGCSE Bulletin, 40(1):402–406, 2008.

[10] Carol L. Binkerd and Michelle D. Moore. Women/minorities in computer science: Where are they? No attention no retention. Journal of Computing Sciences in Colleges, 17(5):8–12, 2002.

[11] Virginia Braun and Victoria Clarke. Using thematic analysis in psychology. Qualitative Research in Psychology, 3(2):77–101, 2006.

[12] Frederick P. Brooks Jr. The Mythical Man-Month: Essays on Software Engineering, Anniversary Edition. Addison-Wesley Professional, 1995.

[13] Peter J Burke. Identity control theory. <u>The Blackwell Encyclopedia of Sociology</u>, 2007.

[14] Tracy Camp. The incredible shrinking pipeline. <u>Communications of the ACM</u>, 40(10):103–110, 1997.

[15] Tracy Camp, W. Richards Adrion, Betsy Bizot, Susan Davidson, Mary Hall, Susanne Hambrusch, Ellen Walker, and Stuart Zweben. Generation CS: The growth of computer science. <u>ACM Inroads</u>, 8(2):44–50, 2017.

[16] Luiz Fernando Capretz. Personality types in software engineering. <u>International Journal of Human-Computer Studies</u>, 58(2):207–214, 2003.

[17] Erin Cech, Brian Rubineau, Susan Silbey, and Caroll Seron. Professional role confidence and gendered persistence in engineering. <u>American Sociological Review</u>, 76(5):641–666, 2011.

[18] Pauline R. Clance and Suzanne A. Imes. The impostor phenomenon in high achieving women: Dynamics and therapeutic intervention. <u>Psychotherapy: Theory, Research & Practice</u>, 15(3):241–247, 1978.

[19] Tony Clear. Affective dimensions of computing education: An 'education as drama' approach? <u>ACM Inroads</u>, 2(4):12–13, 2011.

[20] Eugene A. Cogan. Pursuing professional identity and maturity. <u>Technical Communication</u>, pages 15–17, 1974.

[21] Alain Cohn, Ernst Fehr, and Michel André Maréchal. Business culture and dishonesty in the banking industry. <u>Nature</u>, 2014.

[22] Ann L. Coker, Heather M. Bush, Bonnie S. Fisher, Suzanne C. Swan, Corrine M. Williams, Emily R. Clear, and Sarah DeGue. Multi-college bystander intervention evaluation for violence prevention. <u>American Journal of Preventive Medicine</u>, 50(3):295–302, 2016.

[23] Douglas Comer. The identity crisis in computer science. `https://www.cs.purdue.edu/homes/dec/essay.cs.identity.crisis.html`, 2009. Accessed: 2018-09-07.

[24] Paul F. Conway. Anticipatory reflection while learning to teach: From a temporally truncated to a temporally distributed model of reflection in teacher education. <u>Teaching and Teacher Education</u>, 17(1):89–106, 2001.

[25] Jim Crossley and Pirashanthie Vivekananda-Schmidt. The development and evaluation of a professional self identity questionnaire to measure evolving professional self-identity in health and social care students. <u>Medical Teacher</u>, 31(12):e603–e607, 2009.

[26] Department of Computer Science ABET Committee and Undergraduate and Curriculum Committees. ABET Self-Study Report for the Bachelor of Science in Computer Science at the University of Colorado Boulder. Technical report, University of Colorado Boulder, 2015.

[27] Don A. Dillman, Jolene D. Smyth, and Leah M. Christian. <u>Internet, Phone, Mail, and Mixed-mode Surveys: The Tailored Design Method</u>. John Wiley & Sons, Hoboken, NJ, 2014.

[28] Robert F Dugan Jr. A survey of computer science capstone course literature. <u>Computer Science Education</u>, 21(3):201–267, 2011.

[29] Sebastian Dziallas and Sally Fincher. Aspects of graduateness in computing students' narratives. In Proceedings of the 2016 ACM Conference on International Computing Education Research, pages 181–190. ACM, 2016.

[30] Nathan Lee Ensmenger. 'Beards, sandals, and other signs of rugged individualism': Masculine culture within the computing professions. Osiris, 30(1):38–65, 2015.

[31] Erik H. Erikson. Identity: Youth and Crisis. Norton & Co., New York, NY, 1968.

[32] Joseph J. Ferrare and You-Geon Lee. Should we still be talking about leaving? A comparative examination of social inequality in undergraduate patterns of switching majors. WCER Working Paper No. 2014-5. Wisconsin Center for Education Research, 2014.

[33] Lloyd Fosdick. History of senior projects at CU Boulder. Personal communication. Email dated 2017-03-19.

[34] Stephen T. Frezza. Issues in student valuing of software engineering best practices. In Frontiers in Education Conference (FIE), pages 1–4. IEEE, 2016.

[35] Frances F. Fuller. Concerns of teachers: A developmental conceptualization. American Educational Research Journal, 6(2):207–226, 1969.

[36] Frances F. Fuller, Oliver H. Bown, and Robert F. Peck. Creating Climates for Growth. ERIC, 1967.

[37] Frances F. Fuller and Carol Case. A Manual for Scoring the Teacher Concerns Statement. ERIC, 1972.

[38] Frances F. Fuller, Jane S. Parsons, and James E. Watkins. Concerns of Teachers: Research and Reconceptualization. ERIC, 1974.

[39] Allison Godwin. Personal communication. In-person discussion: 2018-10-06.

[40] Allison Godwin, Geoff Potvin, Zahra Hazari, and Robynne Lock. Identity, critical agency, and engineering: An affective model for predicting engineering as a career choice. Journal of Engineering Education, 105(2):312–340, 2016.

[41] Heather Honoré Goltz and Matthew Lee Smith. Forming and developing your professional identity: Easy as PI. Health promotion practice, 15(6):785–789, 2014.

[42] Douglas Grafel. Follow-up about using student artifacts for research. Personal communication. Email dated 2017-11-10.

[43] Gene E. Hall, Archie A. George, and William L. Rutherford. Measuring Stages of Concern about the Innovation: A Manual for the Use of the SoC Questionnaire. ERIC, 1977.

[44] Gene E. Hall and Shirley M. Hord. Implementing Change: Patterns, Principles, and Potholes. Pearson/Allyn & Bacon Boston, 2006.

[45] J. F. Hall. Recall versus recognition: A methodological note. Journal of Experimental Psychology: Learning, Memory, and Cognition, 9(2):346–9, Apr 1983.

[46] Suzanne Hidi and K Ann Renninger. The four-phase model of interest development. Educational Psychologist, 41(2):111–127, 2006.

[47] Susannah Howe, Laura Rosenbauer, and Sophia Poulos. 2015 capstone design survey: Initial results. In Proceedings of the 2016 Capstone Design Conference, volume 4, pages 6–8, 2016.

[48] Dorthe Høj Jensen and Jolanda Jetten. The importance of developing students' academic and professional identities in higher education. Journal of College Student Development, 57(8):1027–1042, 2016.

[49] Elaine Khoo and Bronwen Cowie. Analysing an online learning community from personal, interpersonal and community planes of development. In Global Learn, pages 4222–4231. Association for the Advancement of Computing in Education (AACE), 2010.

[50] Sara Kiesler, Lee Sproull, and Jacquelynne S. Eccles. Pool halls, chips, and war games: Women in the culture of computing. Psychology of Women Quarterly, 9(4):451–462, 1985.

[51] Alice Y. Kolb and David A. Kolb. Learning styles and learning spaces: Enhancing experiential learning in higher education. Academy of Management Learning and Education, 4(2):193–212, 2005.

[52] John Kolligian Jr. and Robert J. Sternberg. Perceived fraudulence in young adults: Is there an 'imposter syndrome'? Journal of Personality Assessment, 56(2):308–326, 1991.

[53] Jean Lave and Etienne Wenger. Situated Learning: Legitimate Peripheral Participation. Cambridge University Press, Cambridge, MA, 1991.

[54] Yvonna S. Lincoln and Egon G. Guba. Naturalistic Inquiry, volume 75. Sage, 1985.

[55] Jane Margolis and Allan Fisher. Unlocking the Clubhouse: Women in Computing. MIT Press, Boston, MA, 2003.

[56] Robert McCartney and Kate Sanders. School/work: Development of computing students' professional identity at university. In Proceedings of the Eleventh Annual International Conference on International Computing Education Research, pages 151–159. ACM, 2015.

[57] David Merrill and Roger Reid. Personal Style and Effective Performance: Make Your Style Work for You. CRC Press, 1984.

[58] Kerry L. Meyers, Matthew W. Ohland, Alice L. Pawley, Stephen E. Silliman, and Karl A. Smith. Factors relating to engineering identity. Global Journal of Engineering Education, 14(1):119–131, 2012.

[59] Beulah W. Newlove and Gene E. Hall. A Manual for Assessing Open-Ended Statements of Concern About an Innovation. ERIC, 1976.

[60] Aletta Nylén, Mats Daniels, Arnold Pears, Åsa Cajander, Roger McDermott, and Ville Isomöttönen. Why are we here? The educational value model (EVM) as a framework to investigate the role of students' professional identity development. In Frontiers in Education (FIE) 2018, 2018.

[61] Sofia Nyström. The dynamics of professional identity formation: Graduates' transitions from higher education to working life. Vocations and Learning, 2(1):1–18, 2009.

[62] Kevin O'Connor. Contextualization and the negotiation of social identities in a geographically distributed situated learning project. Linguistics and Education, 12(3):285–308, 2001.

[63] National Academies of Sciences. Assessing and responding to the growth of computer science undergraduate enrollments. Technical report, 2018.

[64] David Orenstein. Medical education: Guiding professional identity to prevent burnout. NewsRx Health, page 105, May 2015.

[65] Rick Parker. Student perceptions of success in computer science senior capstone projects. In Proceedings of the 47th ACM Technical Symposium on Computing Science Education, pages 689–689, Memphis, TN, 2016. ACM.

[66] Rick Parker. How do you feel: Affective expressions from computer science senior capstone projects. In 2017 International Conference on Learning and Teaching in Computing and Engineering (LaTICE), pages 35–42, Hong Kong, 2017. IEEE.

[67] Rick Parker. CU Boulder CS capstone study dataset. `osf.io/jyhzm`, Oct 2018.

[68] Rick Parker. Interest-based capstone team formation. Capstone Design Conference (CDC), pages 1–4, 2018.

[69] Rick Parker. Who I am becoming, now: Toward a computer science professional identity instrument. In Frontiers in Education Conference (FIE), 2018, pages 1–9. IEEE, 2018.

[70] Rick Parker. Multiple planes of concern: A study of computer science professional identity formation through changes in participation-based concerns. Computer Science Education, pages 1–25, in review.

[71] David Lorge Parnas. A course on software engineering techniques. ACM SIGCSE Bulletin, 4(1):154–159, 1972.

[72] David Lorge Parnas. Software engineering programs are not computer science programs. Software, IEEE, 16(6):19–30, 1999.

[73] Jane S. Parsons and Frances F. Fuller. Concerns of Teachers: Recent Research on Two Assessment Instruments. ERIC, 1974.

[74] Annie Murphy Paul. How computer coding can increase engagement, provide a purpose for learning. Tech Directions, 75(2):28, 2015.

[75] Anne-Kathrin Peters and Arnold Pears. Engagement in computer science and IT: What! A matter of identity? In Learning and Teaching in Computing and Engineering (LaTiCE), 2013, pages 114–121, Macau, 2013. IEEE, IEEE.

[76] Olga Pierrakos, Thi Kay Beam, Jamie Constantz, Aditya Johri, and Robin Anderson. On the development of a professional identity: Engineering persisters vs engineering switchers. In 2009 39th IEEE Frontiers in Education Conference, pages 1–6, San Antonio, TX, 2009. IEEE.

[77] Tim Rhodus and James Hoskins. Toward a philosophy for capstone courses in horticulture. HortTechnology, 5(2):175–178, 1995.

[78] Barbara Rogoff. Evaluating development in the process of participation: Theory, methods, and practice building on each other. Change and Development: Issues of Theory, Method, and Application, pages 265–285, 1997.

[79] Barbara Rogoff. Observing sociocultural activity on three planes: Participatory appropriation, guided participation, and apprenticeship. Pedagogy and Practice: Culture and Identities, pages 58–74, 2008.

[80] Bruce Sanders. Personal communication. In-person discussion: 2017-01-25.

[81] William Sandoval. Conjecture mapping: An approach to systematic educational design research. Journal of the learning sciences, 23(1):18–36, 2013.

[82] Michael Schneider. Don't fall victim to the odds: Beat early turnover by addressing these 4 emotional needs. Inc., September 2018.

[83] Allison Scott, Freada Kapor Klein, and Uriridiakoghene Onovakpuri. Tech leavers study. https://www.kaporcenter.org/wp-content/uploads/2017/08/TechLeavers2017.pdf, 2017. Accessed: 2017-05-01.

[84] Carroll Seron, Susan S Silbey, Erin Cech, and Brian Rubineau. Persistence is cultural: Professional socialization and the reproduction of sex segregation. Work and Occupations, 43(2):178–214, 2016.

[85] Elaine Seymour and Nancy M Hewitt. Talking about Leaving. Westview Press, Boulder, CO, 1997.

[86] Simon, Judy Sheard, Michael Morgan, Andrew Petersen, Amber Settle, Jane Sinclair, Gerry Cross, Charles Riedesel, et al. Negotiating the maze of academic integrity in computing education. In Proceedings of the 2016 ITiCSE Working Group Reports, pages 57–80. ACM, 2016.

[87] Lee Sproull, David Zubrow, and Sara Kiesler. Cultural socialization to computing in college. Computers in Human Behavior, 2(4):257–275, 1986.

[88] Robert H Todd, Spencer P Magleby, Carl D Sorensen, Bret R Swan, and David K Anthony. A survey of capstone engineering courses in North America. Journal of Engineering Education, 84(2):165–174, 1995.

[89] Gunjan Tomer and Sushanta Kumar Mishra. Professional identity construction among software engineering students: A study in India. Information Technology & People, 29(1):146–172, 2016.

[90] Karen L Tonso. Constructing Engineers through Practice: Gendered Features of Learning and Identity Development. PhD thesis, University of Colorado at Boulder, 1997.

[91] Karen L Tonso. Engineering identity. Cambridge Handbook of Engineering Education Research, pages 267–282, 2014.

[92] Franziska Trede. Role of work-integrated learning in developing professionalism and professional identity. Asia-Pacific Journal of Cooperative Education, 13(3):159–167, 2012.

[93] James Trevelyan. The Making of an Expert Engineer. CRC Press, 2014.

[94] Stephanie F. Ward. What's your ID? ABA Journal, 102(9):28–29, 09 2016.

[95] Etienne Wenger. Communities of Practice: Learning, Meaning, and Identity. Cambridge University Press, Cambridge, MA, 1998.

[96] Jacqueline Whalley, Michael Goldweber, and Harley Ogier. Student values and interests in capstone project selection. In Proceedings of the Nineteenth Australasian Computing Education Conference, pages 90–94. ACM, 2017.

[97] Fran Wiles. Not easily put into a box: Constructing professional identity. Social Work Education, 32(7):854–866, 2013.

<center>**Appendix A**</center>

<center>**Instrument: Semi-structured Qualitative Interviews**</center>

Below is the final revision of the semi-structured interview guide I used in this research work. The instrument guides student reflection on the successes and failures of their capstone project experience. Interviews were conducted with self-selected participants from the 2014-15 and 2015-16 academic years. Analysis of responses supported publications included in Chapter 2 and Chapter 3.

A.1   Interview Guide

Title: Predicting Success: Identifying Factors in Project Success Evaluation by Seniors in Computer Science Education

Version Date: 29 January, 2018

Version: 2

A.2   Introduction of Research

I am researching how participants in the Computer Science departments Senior Project course series (CSCI 4308/4318) at CU Boulder perceive project success. In particular, I am interested in how you consider the successes of your project. Over the course of this interview, we will discuss how you selected your project at the beginning of the course, how you felt your project was evaluated, and how you personally evaluate the success of your own project.

This is not intended as a survey or questionnaire, but is an opportunity for reflection on your

experience. As our interview progresses, we can explore in more depth various topics within these themes as they arise.

A.3   Opening Questions

Have you received the Informed Consent form for participating in this research project?

[If not, pause the interview and provide the Informed Consent form.]

[Invite participant to sign the form granting consent to proceed.]

Do you have any questions about the interview process before we begin?

[For in-person or phone interviews:] May I record our discussion?

A.4   Themes

A.4.1   Project Selection Process

How many projects did you consider during project selection?

What attracted you to some projects?

What drew you away from some projects?

When selecting your project, what did you hope to gain from the experience?

A.4.2   Perception of Project Evaluation

Which of your classes did you feel best prepared you for Senior Project?

Which of your classes or concepts from your degree were you able to incorporate into your Senior Project experience?

Who evaluated your project?

What information was available for them to consider in evaluating the project?

What could have improved the evaluation of the project?

Were there any other factors which they may have considered in evaluating the project?

A.4.3   Self-Evaluation of Project Success

How did you feel as your project was starting out?

How did your feelings about the project change over the course of the school year?

How do you feel about the project now?

In what ways was your project successful?

In what ways was your project unsuccessful?

In what ways does your project experience impact your expectations for future project work?

What would you change if you were continuing to work on the same project?

What would you keep the same?

How has your project experience influenced your career?

What advice would you offer to someone starting into their senior project?

A.5   Closure

We have visited each of the themes I was expecting to discuss during our interview.

Is there anything you would like to discuss further, or which we havent already talked about but you would like to share?

If I have further questions, may I contact you again?

[**If participant is currently enrolled in the senior projects course, or completed the senior projects course within the past 6 months:**] What email address would you prefer that I use to send your $5 gift card to compensate you for your participation in this research study?

[**If participant is currently enrolled in the senior projects course, or completed the senior projects course within the past 6 months:**] Would you prefer a Starbucks or Amazon.com gift card?

[**Stop the audio recording.**]

Thank you for your time!

A.6 Alternative Closure

(Use in case of Participant Withdrawal from Study)

[**Stop the audio recording.**]

As per our discussion prior to starting this interview, you have indicated that you wish to withdraw from the study at this time.

[**If participant is currently enrolled in the senior projects course, or completed the senior projects course within the past 6 months:**] Since you agreed to start the interview process, you still qualify for compensation for your time in the form of a $5 gift card.

[**If participant is currently enrolled in the senior projects course, or completed the senior projects course within the past 6 months:**] What email address would you prefer that I use to send your $5 gift card to compensate you for your participation in this research study?

[**If participant is currently enrolled in the senior projects course, or completed the senior projects course within the past 6 months:**] Would you prefer a Starbucks or Amazon.com gift card?

I realize that you have requested to withdraw from our research study. Will you share any reasons for requesting to withdraw from the study?

Would you be interested in participating in future research studies on this or related topics?

Thank you for your time!

Appendix B

Instrument: Academic Artifacts Consent Survey

The following survey invites people currently or previously enrolled in CS Senior Projects to consent to the use of their academic project work in research. The survey was implemented in Qualtrics.

The approved IRB protocol supported distribution of links to this survey through email and social media (LinkedIn and Facebook). In addition, the protocol included an in-person recruiting and consent process.

B.1   Survey Overview

B.1.1   Q1: Consent to Use of Academic Work for Research

Thank you for letting me use your classwork from CS Senior Projects for my PhD research! I am investigating the influence of CS Senior Projects in preparing students for the transition from the university to the workplace.

This survey gathers basic information so I can retrieve your classwork from the CS department's Moodle archive, meaning I won't need you to do anything in terms of finding classwork. Since everything was submitted for grading purposes, I just need your permission to review your classwork for my research.

This survey lists exactly what individual and team classwork I plan to use. You may list specific assignments for me **not** to use, such as if it might be too personal or if you might have other concerns. I will replace names and references to specific organizations so all classwork will

be anonymous.

Some questions are marked as required, but it's the only way I can get complete information. Please answer as best you can, and write "I don't know" or "idk" if needed.

Please send me any questions you may have: rick.parker@colorado.edu

Thank you!

Rick

B.2 Identifying Information

B.2.1 Q2: Name on Course Records

I will access the CS department's Moodle archive directly to retrieve classwork.

To help me find your classwork, what is your name?

Note: This would be the name used on your academic account in Moodle for CS Senior Projects, not your team name.

B.2.2 Q3: Year of Enrollment

Which academic year did you enroll in CS Senior Projects?

(1) Academic Year 2013-14

(2) Academic Year 2014-15

(3) Academic Year 2015-16

(4) Academic Year 2016-17

(5) Academic Year 2017-18

(6) Academic Year 2018-19

(7) Other: *(text entry)*

B.2.3   Q4: Project Identification

What was your senior project titled?

(If you don't remember, just put "I don't know")

B.2.4   Q5: Project Description

(optional) What was the nature of your project that you worked on for CS Senior Projects?

(If you don't remember, just put "I don't know)

B.3   Consent for Research Use of Classwork

B.3.1   Q6: Overview of Classwork

You did two types of classwork in CS Senior Projects, individual and group work. All classwork was submitted to the class Moodle page. By giving me your permission, I can retrieve your individual and group work from the CS department's Moodle archive after grades are posted.

I need your permission to use your individual work, and permission from all members of your group to use group work.

Individual work is:

(1) Project Preferences Survey

(2) Personal Goals

(3) Communication Styles Questionnaire

(4) Ethics Case Studies and Reflection

Group work is:

(1) Project Presentations

(2) Project Test Plan

(3) Project Deployment Plan

(4) Project Lessons Learned

(5) Project Review Minutes

B.3.2   Q7: Consent for Individual Work

In terms of your **INDIVIDUAL** work, will you allow me to use your individual classwork for my research?

(1) Yes

(2) No

B.3.3   Q8: Exclusions of Individual Academic Work

(optional) From the **INDIVIDUAL** classwork listed above, are there any that you do **NOT** want me to use for my research?

B.3.4   Q9: Consent for Group Work

In terms of your **GROUP** work, will you allow me to use your group work for my research?

(1) Yes

(2) No

B.3.5   Q10: Exclusions of Group Academic Work

(optional) From the **GROUP** work listed above, are there any that you do **NOT** want me to use for my research?

B.3.6   Q11: Contact Assist for Group Members

Only displays if group work consent has been granted.

(optional) I will only be able to use your group work if all team members agree. I will try to contact each team member through their @colorado.edu email address and LinkedIn to ask their permission. Do you have other contact information for any of your team members? Or would you be willing to send them a link to my survey?

B.3.7   Q12: Source Code Access

Only displays if group work consent has been granted.

(optional) Would you share a link to your GitHub repository? Or, would you invite my GitHub account (rickparker) to your project?

B.3.8   Q13: Documentation Access

Only displays if group work consent has been granted.

(optional) Would you share a link to your team document repository, such as a Google Drive folder? Or, would you share a folder with my account (rick.parker@colorado.edu)?

B.4   Follow-up Questions: Career Influence

B.4.1   Q14: Career Influence Questions

Thank you for responding to my questions!

I have an additional open-ended question about the influence of the CS Senior Project course on your career. Will you take a few minutes to reflect on your experience and how your career is moving forward?

B.4.2   Q15: Current Students: Anticipated Influence

For respondents in the current academic year only:

(optional) How does your experience in CS Senior Projects influence your expectations for future projects?

B.4.3 Q16: Previous Students: Reflections on Influence

For respondents in previous academic years only:

(optional) How has your senior project influenced your career (positively and negatively)?

B.5 Wrapping Up

B.5.1 Q17: Anything Else

(optional) Is there anything else you want me to know?

Appendix C

Thematic Analysis Map

Following the Stages of Concern question series from Fuller [38], example concern questions are listed for each of the planes of development analysis [78]. These serve as guidelines for applying the stages of concern across planes of development in thematic coding. Example data extracts following this structure appear in Table 4.1.

C.1   Personal Plane

The personal plane of development focuses on the individual and their capacity to engage meaningfully in work. Guiding questions might include:

(1) [Self Concerns] What is my role? Am I adequate?

(2) [Task Concerns] Is what I'm doing working right?

(3) [Outcome Concerns] Is what I'm doing meeting the need?

C.2   Interpersonal Plane

The interpersonal plane of development focuses on teams, collaboration, and interactions in support of meaningful work. Guiding questions might include:

(1) [Self Concerns] Am I an adequate team member? Can I trust my team?

(2) [Task Concerns] Is our team working right?

(3) [Outcome Concerns] Is what our team is doing meeting the need?

C.3 Community Plane

The community plane of development focuses on the situation of work in social settings. It may be helpful to identify a specific community of practice, as with a computing professional community. The examples listed here focus on software engineering as a professional community of practice. Guiding questions might include:

(1) [Self Concerns] What is my future role? Am I adequate as a software engineer?

(2) [Task Concerns] Am I doing software engineering right?

(3) [Outcome Concerns] Am I meeting a need with my software engineering role?

Appendix D

Instrument: Peer Evaluation Assessment

Four times during the academic year (twice at mid-semester, twice at end of semester), all team members submitted a peer evaluation form. Students consider twelve categories, and assign 600 points per category. An open-ended prompt invites respondents to include comments to justify their proposed weighting.

(1) Productive - produces an appropriate amount of high-quality results

(2) Creative - thinks of novel and viable solutions to problems

(3) Reliable - completes tasks correctly and on time

(4) Responsive - responds to communications appropriately and in a timely manner

(5) Helpful - helps others solve problems when needed

(6) Motivated - interested in doing the best they can on the project

(7) Proactive - helps determine tasks that need to be done and volunteers to do them

(8) Knowledgeable - has good background knowledge for the project and/or is willing to do research to gain the necessary knowledge

(9) Consistent - provides a steady contribution to the project over the course of the semester

(10) Organized - aware of team and individual tasks, deadlines, and commitments and does what's necessary to meet them

(11) Respectful - listens to and considers ideas and input of others

(12) Pleasant - has a good attitude and demeanor and interacts well with others

Appendix E

Full Course Timeline for Each Academic Year

Some variation naturally occurs when aligning the rough course timeline from figure 1.1 with each calendar year, in addition to transitions of course assignments and implementation details. This appendix tracks specific dates of the full course timeline for each academic year of data collection in this dissertation.

Some course changes of interest include the following:

(1) Introduction of Sponsor Fair, replacing Sponsor Presentation Night. First implemented in AY 2014-15.

(2) Addition of midterm and final exams, as part of ABET accreditation process. First implemented AY 2014-15.

(3) Team Dynamics Module, including Bystander Training and Communication Style assessment. First implemented in AY 2014-15.

(4) Meeting Minutes assignments to accompany peer reviews of code, test plan, and deployment plan. First implemented in AY 2016-17.

(5) Lessons Learned assignment for team post-mortem discussion about project outcomes. Formally implemented in AY 2016-17.

(6) Transition from Department Expo to College Expo in AY 2017-18.

Table E.1: Course timeline for five academic years, including artifacts (individual and team).

Event	Artifact	Academic Year				
		2013-14	2014-15	2015-16	2016-17	2017-18
Notice of Intent		Jun 1	Jun 1	Jun 1	Jun 1	Jun 1
Project Proposal		Aug 15	Aug 15	Aug 15	Aug 15	Aug 15
First Day of Class		Aug 26	Aug 25	Aug 24	Aug 22	Aug 28
Sponsor Presentations		Sep 3				
Sponsor Fair			Sep 2	Sep 1	Aug 30	Sep 5
Preference Survey	Indiv	Sep 3	Sep 2	Sep 1	Aug 30	Sep 5
Team Assigned		Sep 10	Sep 8	Sep 8	Sep 6	Sep 11
Risk Management	Team	Oct 8	Oct 6	Oct 5	Sep 19	Sep 27
Kickoff Pres.	Team	Sep 24	Sep 22	Sep 21	Sep 26	Oct 9
Personal Goals 1	Indiv	Sep 30	Sep 22	Sep 21	Sep 26	Oct 9
Midterm Exam			Oct 29	Oct 28	Oct 17	Oct 25
Mid-Fall Eval	Team	Nov 5	Oct 20	Nov 2	Oct 19	Oct 27
Planning Pres.	Team	Nov 6	Oct 20	Oct 19	Oct 31	Nov 6
Bystander Training			Oct 1, 27	Nov 11	Nov 7	Dec 4
Communication Style	Indiv		Nov 17	Nov 16	Nov 9	Nov 15
Fall Break		Nov 25	Nov 24	Nov 23	Nov 21	Nov 20
Ethics	Indiv	Dec 3	Dec 3	Dec 2	Nov 30	Dec 6
Personal Goals 2	Indiv	Dec 2	Dec 1	Nov 30	Dec 5	Feb 2
Final Exam			Dec 10	Dec 9	Dec 7	Dec 13
End of Fall Eval	Team	Dec 20	Dec 18	Dec 17	Dec 15	Dec 21
Winter Break		Dec 23	Dec 22	Dec 21	Dec 19	Dec 25
Status Pres. 1	Team	Jan 21	Jan 20	Jan 25	Jan 23	Jan 22
Code Review Minutes	Team				Jan 23	Jan 22
Test Review Minutes	Team				Feb 20	Feb 19
Status Pres. 2	Team	Mar 9	Mar 9	Mar 7	Mar 6	Mar 5
Mid-Spring Eval	Team	Mar 18	Mar 2	Mar 7	Mar 10	Mar 9
Personal Goals 3	Indiv	Jan 28	Apr 20	Apr 4	Mar 13	Mar 12
Spring Break		Mar 24	Mar 23	Mar 21	Mar 27	Mar 26
Poster Pres.	Team	Apr 22	Apr 22	Apr 11	Apr 10	Apr 9
Exposition		Apr 29	Apr 27	Apr 26	May 2	Apr 27
Lessons Learned	Team				May 1	Apr 30
End of Spring Eval	Team	May 8	May 4	May 5	May 11	May 10