INVESTIGATING COMPUTATIONAL IDENTITY: A QUALITATIVE STUDY OF UNDERGRADUATES PARTICIPATING IN A THERMODYAMICS COURSE

by

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To my family, both given and chosen.
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ABSTRACT

Biological engineering includes a higher representation of women (Yoder, 2015) than most science, technology, engineering, mathematics and information technology fields, while computer science has seen a precipitous decline in women's representation. However, disciplines like biological engineering are becoming more computationally intensive (Savage, 2018), incorporating computational skills like computer programming. As biological engineering is adapting tools and practices from computer science, there is potential that the factors that have contributed to the decline in the participation of women in computer science may impact women's participation in biological engineering as well. In engineering education research, discipline-based identity research is one framework that is used to understand retention and persistence issues because students' sense of self as an engineering and belonging is a critical factor when it comes to deciding to stay or leave discipline.

The current study adopts the framing of identity, which comes from social identity theory (Stryker & Burke, 2000) and symbolic interactionism (Burke & Stets, 2009). Recently, some work has emerged on understanding the computing identity of computer science and engineering students (Garcia, Hazari, Weiss, & Solis, 2019) and the computational identity of K-12 mathematics students (Kong & Wang, 2020). However, a clear gap exists in research that explores the computational identities of undergraduate engineering students. This dissertation utilizes an established theoretical framework from computer science education research for understanding computing identity (Mahadeo et al., 2020). For the current study, the operationalization of computational identity for research in engineering could provide a transition from one discipline (computing) to another (engineering) because of a similar skillset (programming) while also contributing to the engineering education body of knowledge.

For this qualitative investigation, 23 semi-structured interviews were conducted with undergraduates who were enrolled in a computationally intensive thermodynamics course. During the analysis phase, coding was inductive as well as deductive in nature; in vivo coding used participants' words from participant's sentences as codes while the interviews were also coded for constructs and sub-constructs based on the theoretical framework. Axial coding helped to combine related codes that emerged from the inductive and deductive coding into themes, and the themes addressed each of the research questions.

The findings present an emergent thematic definition of a "computational person" constructed from students' perceptions and experiences. A detailed description of a computational person based on student perspective came out as someone who is proficient with mathematics, logical thinking, and computer programming and can make rational decisions and encompass multiple perspectives towards problem-solving and solution representation. Participants also talked about their own computational identity in relationship to how they defined a computational person. Most of the participants described that their computational identity as "in the making."

This study's second contribution is the investigation of congruence between the participants' computational identity and other identities they held: gender, engineering, and artistic. The qualitative analysis revealed that for some students there are incongruences between an artistic/creative identity and a computational identity and incongruences between being female and having a computational identity. In contrast, engineering identity and computational identity were found to be congruent. The interview participants also noted ways that pedagogical approaches used in the thermodynamics course supported the development of computational confidence. This study's findings support computational practice and cooperative learning-based instruction for computational identity development. Finally, the study proposes future directions for engineering instructors, students, and engineering education researchers who want to promote and or study computational identity development.

1. INTRODUCTION

1.1 Problem Statement: Computational identity as a factor in the underrepresentation of women in STEM

The participation of women in STEM has increased in recent decades, with women earning 37% of undergraduate STEM degrees in the United States in 2016 (National Science Foundation, 2017). However, women remain underrepresented in specific fields, such as engineering and computer science, where only 21% of engineering majors and 19% of computer science majors are women, respectively (Corbett & Hill, 2015). The percentage of girls and women in computing activities decreases from childhood through professional careers (Sharma, 2020). The reasons for this disparity must be understood and reduced or the reasons of equal participation, social justice, shifting the focus on the marginalized groups, and finally because of a large growth in job demand for careers related to high technology sectors (Chege, 2020).

The acquisition of digital skills (ability to operate computer software and program) is more important than ever and having digital skills is a critical professional qualification (Tedre, 2016; Weintrop, 2014). Computer science and computer modeling are among the top ten skills required in the engineering job market in this era (Doyle, 2020)—highlighting the importance of learning and acquiring computing skills in higher education. Kumar & Ekren (2020) suggested that universities should integrate the new, innovative, and multidisciplinary approaches in teaching to stimulate digital skills in higher education, making students suitable for cross-functional roles. Computation and computational modeling skills are currently part of undergraduate academic requirements in almost all engineering disciplines (ABET, 2020). There is a greater need for engineers in the workforce with computing skills, yet the field of computing alone is still suffering from student decline of 30% to 18% over the last two decades (NCES, 2017), significantly reducing women's participation (White & Massiha, 2016).

Internal data from Purdue (about job placement for graduates of agricultural and biological engineering) suggests potential occupational sorting of men and women into higher and lower computational intensity jobs. The substantially lower entry rate of women into engineering graduate programs nationwide may also reflect this sorting. Hence, there is a possibility that computational instructional practices and experiences of computational and mathematical modeling in class could be a factor in gender disparities within individual engineering disciplines, but it remains unclear to what extent this intersection occurs. There is a need to understand issues related to motivation for studying engineering, persistence in an engineering curriculum, and academic retention in computational engineering disciplines—all common themes that speak to the underrepresentation issue.

Recent research on engineering identity informs us that a sense of belonging is a critical factor in retention and engineering persistence (Godwin, Cribbs, & Karumova, 2019). Engineering identity serves as a framework to understand student's sense of belonging in engineering because if a student is not able to see themselves as the kind of person that can do the work of their discipline, they may not feel like that career pathway is "for them" and they may decide to switch or leave engineering (Godwin, 2016). The work conducted for his dissertation explains the development of computational identity—that is, the way that people perceive themselves and others' perceptions of them as competent, interested, and recognized or not at programming and mathematical modeling—as a factor impacting student retention. This dissertation presents the argument that as engineering disciplines are becoming increasingly computational, investigating computational identity is becoming increasingly important to understand if the growing demand for computational skills affects the retention of women in engineering.

1.2 Computation is skills as abilities to perform Computational Thinking

Defining "*what is computation?"* is like expressing "*what is life*?" Various attempts have been made to create a definition, but it remains unclear with the new usage of technology and application processes. Initially, computation meant the calculation actions of a human computer (Turing, 1948). Later, the computation was routinely associated with electronic computers (Leeuwen & Wiedermann, 2019) and information transformation. Others have defined "computation as a process evoked when a computational agent acts on its inputs under the control of an algorithm" (Denning, 2010, pp. 1). Conery (2010, pp. 4) defined computation as "a sequence of simple, well-defined steps that lead to the solution of a problem. The problem itself must be defined exactly and unambiguously, and each step in the computation that solves the problem must be described in precise terms." This definition of computation also supports a clear description of computational thinking as "Formulating problems in a way that enables us to use a computer and other tools to help solve them, Logically organizing and analyzing data, Representing data through abstractions, such as models and simulations, Automating solutions through algorithmic thinking, Identifying, analyzing, and implementing possible solutions to achieve the most efficient and effective combination of steps and resources, Generalize and transferring this problem-solving process to a wide variety of problems" (Bar & Harrison, 2012, pp. 1). Hence, computation has evolved from performing calculations to having skills and abilities to perform calculations through computational devices like computers.

1.3 Purpose of the Study and Goals

In the early days of computing, the 1940s, and 1950s, women made up the majority of computer pioneers (Smith, 2013). As the computing discipline became more prestigious it became more masculine (Ensmenger, 2010). The percentage of girls and women in computing activities decreases along from childhood through professional careers Leech (2007). At the same time, the current barriers to computing careers for women and underrepresented racial minorities (e.g., inadequate advising, lack of mentors and role models, discrimination, bias, limited access to financial aid, and lack of attention to and accommodation of family issues acting as barriers), is a matter of equal representation. Computing culture in the present age has reflexive sexism (men are believed to be inherently good at programming (Beyer, 2014), and racism is still deeply ingrained, impacting the experiences of people participating (Wong, 2017).

However, all of the fields of engineering fields are also becoming computationally intensive because of growing demands for computing skills from industry and incorporation of computational tools in the curriculum and pedagogy. One of the areas adapting rapidly to this increasing computational intensity is biological engineering (Savage, 2018). Biological engineering enjoys higher participation rates of women compared to computer science and other engineering disciplines (Bossart & Bharti, 2018). Similar problems of masculine norms and sexism can escalate to biological engineering because of the growing demand for computational skills and the introduction of computationally intensive pedagogy because of existing stereotypes associated with computer science students. Masculine norms, already existent in computer science students are not asking questions (being anti-social), narratives of intelligence, and work independently (Ensmerger, 2012).

The new computational trends in the field bring benefits in increasing skillset. With an increase in masculine norms there is a risk that students who identify as feminine may not feel like they fit or "belong" in engineering. Researchers and practitioners are making efforts to retain women in computer science and engineering disciplines by understanding the barriers to a sense of belonging in these disciplines (Giannakos, Pappas, Jaccheri, & Sampson, 2017; Frieze & Quesenberry, 2015; Hill, Corbett, & Rose, 2010). A part of identity formation depends on the sense of belonging in a social group because social recognition is a component of identity formation (Shotter, 1993). Understanding the student's perspectives of their computational identity helps to identify if they feel a sense of belonging in the context of a computationally intensive environment and if students have any sort of experiences while performing computational activities in engineering that are in opposition to their sense of belonging. While there is existing research on identity, and disciplinary identities i.e., STEM identity, and engineering identity (and this is discussed more in Chapter 2), there is a paucity of research on computational identity.

To support change that could reduce gender inequality and promote women retention in engineering and Computer Science fields, this dissertation is focused on understanding better the biological engineering students' experiences in a computationally intensive course. Biological engineering was chosen as the specific focus because the instructors teaching thermodynamics course in biological engineering department revised the curriculum of the course by introducing computational thinking in the course and were interested to know how the changes affect engineering identity. Additionally, the absence of literature on computational identity, especially among engineering students who are not computer engineering students, means there is a research gap. This research fills the gap of understand the interplay between engineering, computational, and gender identity. Because it is important to understanding if students experience congruence or incongruence between their gender identity and a computational identity because when identities are in congruence they grow together; however when in conflict one of the identities gets minimized (Miller et al., 2017).

This work is essential to the engineering education community primarily because it defines the computational identities of undergraduate engineering students and explores their description of computational identity, the experience of gender, and pedagogies that helped with computational identity development. Secondly, which pedagogical strategies support the development of computational skills and identity formation and retention efforts. Lastly, these findings can inform initiatives for improving engineering culture and promoting diversity in fields that are becoming increasingly computational and may suffer from unequal gender participation.

1.4 Role of Researcher

I come from a computer engineering background and have served as a computer science educator at higher education before becoming an engineering education researcher. I am trying to understand how computational identity is developed in engineering undergraduates and if computational identity is necessary for women's retention in engineering. The context of this study is an undergraduate sophomore thermodynamics class where I participated as an observer and researcher. Except for the theoretical interest in the topic, part of my motivation to engage in this topic of computational identity and gender was this intention to learn about student experiences.

I believe my gender, prior knowledge, and engineering and computation experiences influence my research motivation and conduct. It is difficult for me to judge what effect I may have had on the research setting or any of the participants. The participants knew that I was a doctoral candidate and an engineering education researcher and that the interviews they were participating in would become the data for my doctoral thesis. All of the individuals that I interviewed participated in the interviews voluntarily. One of the participants replied to my question of "what keeps you motivated to perform a computational task?" by saying, "just the feeling that you get at the end of a computational task. Like, I am sure you know, when you are like working so hard on code and then you like get it, it's like such a good feeling"; in this case, when she said, "I am sure you know," I believe that she had an idea that I can program.

There were times when I was still with the participants, or as I was going through transcribing and analyzing the interviews, that I got teary eyed because I could feel the participants' frustration or could feel how they would have felt. I was profoundly empathetic and felt helpless.

1.5 Significance of the Study

In 2016, although women earned 57% of bachelor's degrees overall and 50% of bachelor's degrees in science and engineering, women only accounted for 18% of bachelor's degrees in the computing sciences (Stephenson et al., 2018). A Stanford University study measured female retention in a computing program between the first and second years and found that the participation of women dropped from 47.5% to 38.6% (Redmond, Evans, & Sahami, 2013). As discussed in more detail in this study's literature review, some research has been devoted to understanding the experiences of students in computer science and computer engineering about computing identity. Additionally, several studies have explored computing and gender for promoting diversity and addressing issues related to e retention and persistence in programming and technical fields.

This dissertation helps in understanding individual students' perceptual or experiential processes in developing a computational identity. Modern engineering is becoming adaptive to incorporating learning tools from more computational fields like computer science. This study is also novel because it investigates the experiences of engineering students who participate in a computationally intensive course outside computer science and computer engineering.

This research explores the computational identity of engineering students enrolled in a computationally intensive biological engineering course at the undergraduate level, intending to identify findings that can increase the retention of women retention in computationally intensive fields and increase diversity more broadly.

1.6 Definition of Key Terms

Identity: a two-faceted perspective based on self and others: how does the student describe oneself, and how do others describe or perceive the person (Erickson, 1968).

Computation: solving a problem by performing algorithmic steps to reach a suitable and efficient solution (Bar & Harrison, 2012).

Computing Identity: "Computing identity includes students' self-perceptions about recognition, interest, and performance/competence" (Garcia et al., 2019). It is defined as specific to computer science and computer engineering. However, it can span across disciplines which require similar skills.

Discipline-Based Identity: In this framing, "disciplinary identity is described as how students envision themselves in the context of a domain or discipline" (Sarmient0, 2018).

Computational Self-efficacy: is defined as one's belief in one's ability to succeed in specific situations or accomplish a task that requires programming and mathematical skills. One's sense of self-efficacy can play a significant role in approaching goals, tasks, and challenges (Bandura, 1994).

Skills and Capabilities: (associated with engineering and computation): Ability to do and understand practices and concepts like Programming, Problem Solving, and Mathematics (Lave & Wenger, 1991). Dependent on background knowledge, competence, and interest.

Sense of Belonging: a student's feeling of acceptance and being a part of a social group in the engineering community is a critical factor towards engineering identity attainment (Meyers, Ohland, Pawley, Silliman, & Smith, 2012).

Recognition: The looking-glass self-theory (Cooley, 1902) suggests that the reactions of others in the environment shape self-perceptions of a person. Also, being recognized by others as a certain kind of person is strongly associated with identity development (Hazari, Sonnert, Sadler, & Shanahan, 2010).

Gender: (gendered socialization theory) A self-perception based on biological and physical appearance. Socially constructed through socially dominant images (Reinking & Martin, 2017). Students participating in the study provide self-reported gender pronouns.

Interest: an affective factor to participate or engage in engineering or computation (Hazari et al., 2010).

Persistence: Persistence has been conceptualized as a behavioral commitment to studies (Roland, De Clercq, Dupont, Parmentier, & Frenay, 2015). This behavior consists of continuing a task even if the individual encounters difficulties (Burres et al., 2013).

Cooperative Learning: A type of active learning pedagogy in which students are given roles in a team to accomplish a specific task together (Smith, 1995).

1.7 Overview of Dissertation

This section provides this dissertation's structure on the investigation of computing/computational identity amongst undergraduate engineering students who enrolled in biological and biomedical engineering discipline. The study at hand is divided into five chapters. In Chapter 2, I have provided an overview of the current literature on the following,:

1) how engineering identity is used to understand retention and persistence issues,
2) prior work on discipline-based identities in STEM to explore any existing related work on computational identity which provides a foundation for the current study
3) how computation is very gendered, and how gender is deeply embedded in this research
4) how computational thinking pedagogy and active learning settings of group work are most suitable to understanding computational identity.

Chapter 2 ends with a discussion of two theoretical frameworks that guided the study: computing identity and social identity theory.

Chapter 3 provides detailed descriptions of the research question, methodology, and methods used to conduct the study with a detailed account of the participants, setting description, data collection, and analysis description. The framework incorporated to ensure the quality and trustworthiness of data collection and data analysis. Approval of the institutional review board for data collection is also included.

Chapter 4 organizes and reports the study's main findings, including the presentation of relevant qualitative data. Results are built logically from the problem, research questions, and the research design and are organized and elaborated around the three research questions.

Chapter 5 connects the findings from each research question to previous literature, summarizes and concludes the study, discussed limitations, and looks into further development and applications for instructors, students, and engineering education researchers.

2. LITERATURE REVIEW

This chapter examines significant research findings related to computing identity, computational thinking, and gender in higher education, focusing on engineering. This chapter establishes the need to investigate computational identity in engineering students. A growing body of education scholarship (Eliot, 2011, Rodriguez, Lu, & Bartlett, 2018, Godwin et al., 2019) finds that developing engineering identity is a critical factor for the persistence of engineering students during their undergraduate programs.

2.1 Engineering Identity as a Lens to Understand Retention and Persistence

"Identity refers to the roles of a self, constructed by meanings that a person attaches to the many roles they play in their world" (Stryker & Burke, 2000). A person can have more than one identity at a given time; these identities become salient based on the context where the person is situated. The effects of the interplay of all of these identities on their decision to stay in or leave engineering. I use McCall & Simmons's (1966) assertion that identity is an ongoing negotiation between self and external structures.

The literature on the modern framing of engineering identity emerges from a sociocultural theory of identity as conceived by foundational research by Gee (2000) and Holland (1998). From a sociocultural perspective, engineering identity formation is an ongoing process and is dynamic concerning how a person interacts in the engineering environment with other people (Gee, 2000; Wenger, 1998). Several researchers have studied and defined engineering identity; for instance, Morelock (2017) described a systematic review of 19 studies that define engineering identity and methodologies used to study engineering identity. Identity is an essential construct in understanding student persistence, the process of learning, and a way to promote equity in STEM (Godwin et al., 2019).

Across several studies, engineering identity involves seeing oneself in the role of being an engineer, being recognized as an engineer. Studies that have recognized that engineering identity involves seeing oneself in the role of engineering have explored this by conceptualizing engineering identity as the knowledge, emotions, abilities, and experiences surrounding one's roles as an engineer (Eliot & Turns, 2011), and by examining the configuration of roles an engineer assumes in the workplace, which varies based on the environment (Hatmaker, 2013). Researchers have also highlighted that recognition plays a role in engineering identity. Rodriquez and colleagues (2018) defined engineering identity as a measure of an individual's perception of their recognition as an engineer by others, competence as an engineer, and interest in engineering, which combine to create an accurate assessment of how strongly a student sees themselves as an engineer. Mann, Prue, Fons, & Fae (2009) expressed engineering identity as a combination of an individual having a self-belief about being an engineer and others recognizing the individual as an engineer at the same time. Tonso (2014) noted that when someone is referred to as an engineer in everyday settings, it signals the individual being referred to as having an engineering identity because “the individual” belongs to a community of engineers. Fleming (2011) described the experience of acquiring personalized value and meaning from engineering activities contributes to engineering identity development. Peters and Pears (2103) describe engineering identity as an individual establishing a relationship between themselves and the engineering community Additionally, Some researchers (e.g., Godwin, Potvin, Hazari, Lock, 2013; Eliot & Turns, 2011) have described how engineering identity is manifested as having constructs that relate to performance/competence, interest, knowledge, abilities, and experiences related to engineering in addition to recognition by others. Across these studies, engineering identity involves seeing oneself in the role of being an engineer, being recognized as an engineer by others, participating in the community of engineers, and having the abilities and knowledge to perform engineering.

Godwin et al. (2019) reported that there is no universal STEM identity because STEM identity depends on the individual and the context in which that individual is situated. In the same way, there is no universal engineering identity, and within engineering, the engineering identities can vary based on context. The concept of discipline-based identity helps us understand a sense of belonging in engineering disciplines because engineering varies across multiple disciplines. Discipline-based identity research in STEM has been reported on defining and understanding the development of mathematics (Solomon, 2007), science (Carlone & Johnson, 2007), physics (Hazari et al., 2010), and computing (Garcia et al., 2019) identities. The following paragraphs describe related work in discipline-based identity research across STEM disciplines.

Research related to STEM identity suggests that a STEM identity is a powerful STEM association or affiliation. These associations are evidenced by competence, efficacy, and interest in the content and procedures of STEM and verified by individuals' performance in STEM activities and recognition of those activity performances by STEM professionals (Carlone & Johnson, 2007; Hurtado et al., 2009; Thiry et al., 2012). In order to help promote a STEM identity, not only is the atmosphere in which an individual encounters and interacts with STEM significant, but the perception of resources and support (both tangible and intangible) helps in the creation of a STEM identity (Merolla et al., 2012).

Similarly, in the context of science identity participation in the community is an important aspect of identity development. Malone et al. (2009) proposed that a science identity requires a sense of involvement in the science community that one is considered worthy of participation. I will argue that's in addition to striving for recognition, having a sense of belonging and worthiness also contribute to establishing a science identity. Students with science identities develop a positive self-perception of themselves as scientists (Huang, Nebiyu, Walter, 2000; Lewis, 2003). When students assert themselves as a science learner, as someone who learns about science, as someone who uses science, and as someone who contributes to science, a student is considered to have taken up a science identity (Schon, 2015).

Archer et al. (2010) reported that young students who enjoy engaging in science activities may not take up a science identity because doing so would clash with their intensely held gender identities. In Carlone & Johnson's (2007)'s study of women's science identity, science identity was viewed as women's perceptions about their science experiences and how society defines possible meanings. The framework from Carlone's study suggested that student science identity is made up of three dimensions: competence, performance, and recognition. Three science trajectories were identified based on the importance of recognition by others for women as a research scientist (self and society recognized as scientists), altruistic scientist (took science as a vehicle for altruism and gave new meanings to science), and disrupted scientist (these women sought recognition in science but were not given the required credit from meaningful others). Findings suggested that some women (disrupted scientist category) who pursue STEM degrees face barriers that can be directly traced to their gender and other background characteristics that interact with gender. When women were known not for their competence and intellectual abilities but as women or as members of their racial or ethnic group, women with disrupted scientific identities had their bids for recognition dismissed. Conflict problems can often create contradictions between celebrated and desired or aspirational identities. An. An example of a conflict problem is if a woman is good at programming skills but sees the dominant celebrated stereotype of a computer scientist as an antisocial white male it may deter women from becoming interested in the field. Carlone and Johnson (2007) found that while competence and performance were significant, the creation of science identity in women could not be predicted without recognition.

Individuals who perceive STEM as incompatible with their identity face the choice of either changing their identity to match expectations of preexisting STEM cultures or letting go of STEM disciplines. In an investigation of students' physics identities, Hazari et al. (2010) demonstrated that students who have a higher sense of physics identity are much more likely than other students to anticipate having a physics career. The study's novelty was that the constructs of identity, interest, recognition, performance/competence (i.e., ability to achieve good grades and the ability to understand concepts) were quantitatively measured for physics.

An additional STEM-related identity that warrants further investigation is computational identity. In recent research, Garcia et al. (2019) conducted one of the first studies of computational identity. Garcia and colleagues studied students who were high-achieving and underserved in undergraduate computing. Computing identity was conceptualized to include students' self-perceptions about recognition, interest, and performance/competence. According to preliminary findings, female students had a lower computing identity than male students, especially in terms of computing recognition and overall computing identity. The need for defining and investigating computational identity is further discussed in the proceeding section.

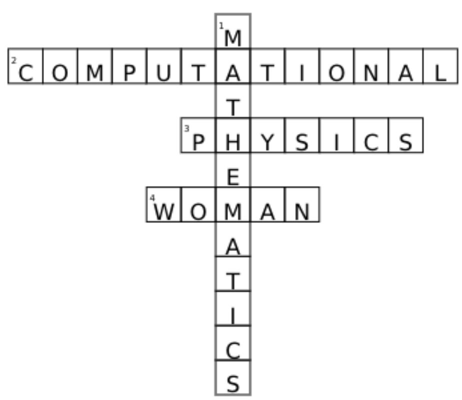


Figure 1. Multiple Possible Identities of a STEM student

Identity is complex and complicated topic because people can have many different identities at the same time. Figure 1. Represents a possible combination of different identities an engineering student can possess, the student could identify as a woman and have engineering, physics, computational, and mathematical identities at the same time. Different identities are intertwined and influence each other.

2.2 Computational Identity

Recent studies have begun to describe how computer science students exhibit and develop computational' identity. Some identity studies have examined how computer science students perceive their computer science engagement and information technology meaningful to investigate the interest component of identity development (Peters & Pears, 2013). Garcia et al. (2019) reported recent work on computing identity within undergraduate computer science and computer engineering which sheds light on students' self-perceptions about recognition, interest, and performance/competence, which are critical components of identity development. The findings from Garcia et al.'s (2019) study suggest that even amongst high achieving students, female participants had less of a computing identity than male students. In another recent study, Kapoor & Gardner-McCune (2019) researched computer science undergraduate students and how they professionally identify themselves. Kapoor and Gardner-McCune defined professional computing identity as a transformation of interest in computing to self-perception, engaging with computing as a career. They found that these students explore computing professions through their involvement in professional development activities, informal activities, coursework, and negotiations with people in the broader community. However, computer science identity or computing identity was not clearly defined. For undergraduates, computing identity studies are limited to only computer science, software engineering, and information technology undergraduate students (Kapoor & Gardner-McCune, 2019; Garcia et al., 2019; Peters & Pears, 2013). Little work has been done to understand and investigate undergraduate students' experiences who are participating in computational activities outside computer science and information technology. Understanding these experiences will help in investigating how can students' interest, competence, and recognition can be fostered for computational identity development which will help with retainment efforts.

A recent study (Kong & Wang, 2020) defined computational identity as “an ongoing mental construction process of self-identification resulting from total immersion in feelings and experiences of programming activities at school”. The study conceptualized computational identity with the following four components: (1) programming engagement, (2) programming affiliation, (3) programming actualization, and (4) programming goal setting. Kong and Wang (2020) reported that computational identity is not necessarily fostered by learning computing skills and requires explicit instructional design consideration. However, Kong and Wang's definition of computational identity was developed in the context of elementary-aged children and is based on Brennan & Resnick’s (2012) discussion of computational thinking and social identity theory (Jenkins, 2008). However, further investigation is needed to better understand computational identity in higher education because of the varying definitions of computational thinking in the literature and the skills associated with computation in engineering. Understanding undergraduates' experiences in computational fields and how they associate their identity with these experiences is crucial for attracting and retaining students in engineering and computational programs. In the next section, the need for investigating computing identity research in tandem with gender is established.

2.3 Gender and Computing

The participation of women in STEM has increased in recent decades, with women earning 37% of undergraduate STEM degrees in the United States in 2016 (National Science Foundation, 2017). Leech (2007) reported that girls do engage with computers, but few consider computing a potential career while women's participation in computing careers is still uneven. Gender is essential in studies of engineering and computational identity because of gender disparity issues in engineering and computational disciplines (AAUW, 2010). A part of the problem is socio-cultural factors such as gender stereotypes, subtle biases against girls in early education, and lack of encouragement and exposure, essentialist thinking about inherent skills and capacities (Frieze & Quesenberry, 2013; Lichtenstein, 2014). These forces continue throughout formal schooling through university education leading to a drop-in confidence level. As a result of the large contextual factors, some women underestimate their capabilities in using computers and technologies in general due to less confidence in taking up computational programs (Fisher & Margolis, 2002; Frieze & Quesenberry, 2013).

Research by Wong (2017) has shown that negative stereotypes associated with computer science and programming can be a barrier to participation in computer science or computationally intensive fields. Wong (2017) reported that traditional identities of computing people who are clever but antisocial prevail in young people who are users of technology, which can be unattractive for youths, especially girls. Other studies have shown that competent computer science students and programmers are often imagined through stereotypes that include characteristics of being smart and committed and lonely, stubborn, and antisocial (Cohoon & Aspray, 2006; Margolis & Fisher, 2002). There is a long-standing stereotype that women are fundamentally unfit to be programmers, which may lead women to feel that they do not belong, have less confidence, or have less desire to participate in technical roles in computational projects (Spieler, 2020; McGurren, 2014). Another difficulty women may face in masculine-dominant fields is stereotypes that promote the idea that women are less competent than men. When salient, this stereotype can promote a sense of threat and reduce women's motivation in a domain, leading to its abandonment (Davies, Spencer, Quinn, & Gerhardstein, 2002). These stereotypes make computing unattractive (Cohoon & Aspray, 2006; Margolis & Fisher & Margolis, 2002). Tonso (2006) explained that a community is a crucial part of feeling a sense of belonging as an engineer. Simard et al. (2008) explain that computing and information technology is a field whose culture is "masculine, white, and heterosexual in nature" (pp.8) and is associated with "hard programming, obsessive behavior, and extensive working hours" (Turkle,1995; Margolis, Fisher, & Miller, 1999). Computing being a masculine discipline presents these stereotypical characteristics, and both men and women who want to depict acceptance in this masculine field adapt to these characteristics (Connell, Raewyn, & Rebecca, 2015; Akpanudo, Huff, Williams, & Godwin, 2017).

When a student sees a domain or role as congruent with self, they can quickly develop an identity associated with that role or discipline (Miller et al, 2017). When incongruence happens, it causes identity conflict that can lead to coping strategies to minimize one's identity in a particular context to create fit or to leave (Miller et al, 2017). It could be possible that when students who engage in computing see the stereotypes, antisocial nature, and masculine social norms of computing can convey cues that negatively impact women’s interest or their belonging in the discipline. Others may conform to masculine norms to create a fit and author an identity within this field.

One of the primary reasons for this uneven existence is that there are few female role models in the computing and tech industry exist. The media images of the most successful people in the tech industry are White and privileged men, such as Bill Gates, Jeff Bezos, Steve Jobs, and Mark Zuckerberg (Mendick & Francis, 2012). Having more men as role models augments stereotype threat in women. These stereotypes can affect female students' sense of belonging and affect their progress towards attaining a computational identity or seeing themselves as a computational person.

A study by Simard, Henderson, Gilmartin, Schiebinger, & Whitney (2008) examined specific barriers that exist for women in Information Technology, as this is a STEM field where the number of women in the industry has declined since 1996 (Information Technology Association of America, 2005). Women are much more likely to be seen as token members in the tech industry Wong (2017). Because women are much more likely to be solo members (being the only women in a professional committee/group) in fields like computing, they also may be more likely to be seen as out-group members. Women are token members in such a setting, and work-life balance might also be challenging to achieve in such an environment because of having more family responsibilities (i.e childcare; Cuny & Aspray, 2001).

Self-theories of intelligence, which focus on people’s beliefs about their personal abilities, are suggested as another possible cause of women's underrepresentation in computing and engineering (Fisher & Margolis, 2002). Garcia et al. (2019) showed that women who were high achieving in computing showed signs of feeling less acknowledged as "computing people" than male students.

The low participation of women suggests that gender acts as an essential lens for self and society in having a sense of belonging in computational fields. There are initiatives like Girls Who Code and Code First: Girls trying to make a difference in introducing girls to programming skills and providing girls the opportunity to develop computing skills earlier in life to create a sense of belonging in them towards becoming a “computational person”. However, to promote women and other genders in computing and engineering, attention should be focused on cultural change and conditions in the environment. Understanding differences in gender experiences in computational fields is crucial to retaining more women into engineering and computational programs.

2.4 Computational Thinking Instruction, and Cooperative Learning

Computational thinking is an integral part of computer science (Calderon, 2018), and competence in computation is critical to developing computational identity (Garcia et al., 2019). One way of developing competence in computation is through computational thinking-based pedagogy. Research on computational thinking has generated new pedagogical approaches for computer science education that foreground the higher-order computer science concepts, use contextualized problem solving, and de-emphasize syntax (e.g. Simard et al., 2008; Dodds, Alvarado, & Libeskind-Ha, 2012). Further, computer science education approaches that downplay prior coding skills and use team learning have shown increased persistence of women in computer science, most prominently at Harvey Mudd College (Dodds et al., 2012). Advocates for computational thinking instruction have supported the implementation of these approaches across disciplines, and there have also been substantial efforts towards popularizing computational thinking instruction in K-12 education (Yadav, Hong, & Stephenson, C., 2016). In contrast, attempts to integrate computational thinking in undergraduate education, outside of computer science, have been more dispersed (Lockwood, 2017). Some efforts are being made towards understanding computational thinking skills and challenges faced by students in biological engineering (Magana & Silva, 2017; Shoaib, Cardella, Madamanchi, & Umulis, 2019).

To investigate computational identity in tandem with gender in the context of higher education, one of the possible approaches is to explore how students engage in group work in an active learning setting. Through active learning, students collaborate and participate in learning exercises. Project-based Learning (PBL) is a form of active learning (Bell, 2010). This instructional approach is extensively applied in engineering that adapts curriculum concepts and objectives through a project, representing a "key strategy for creating independent thinkers and learners" (Bell, 2010). Many classes in engineering are shifting to group work and active learning, especially project-based learning in engineering (De los Ríos, Cazorla, Díaz-Puente, & Yagüe, 2010). One challenge that engineering educators have considered in recent work is including active learning approaches in large classes (i.e., 100 or more students). In one study, Georgiou & Sharma (2015) reported that incorporating active learning in large thermodynamics classes led to significant improvements in learning outcomes.

Cooperative learning is a form of active learning in which small teams of students work on a specific task or project together to achieve desired results (Johnson, 1994). Cooperative learning and engineering education are intrinsically linked to each other (Moussavi, 1996). During formal cooperative learning, a small group of students is assigned roles to perform tasks associated with the project. Instructional decisions are made in a cooperative learning format by formulating academic objectives, defining the group size, selecting a method for assigning students to the different groups, defining group members' roles, and providing the materials students need to complete the respective assignment (Trytten, 2001).

The research on the cooperative learning approaches used for engineering students has shown that small group learning effectively fosters academic achievement and attitudes (Mourtos, 1997), encouraging positive attitudes towards learning new tools, increasing persistence in classrooms, and preparing students for teamwork in an industry career. Cooperative learning provides more effective ways for students to discuss, teach, and learn in student groups (Antov, Pancheva, & Santas, 2017). Recently, collaborative learning has also been a successful teaching pedagogy in increasing student retention in large-scale computer science classrooms (Peteranetz & Soh, 2020).

In addition to the research that shows learning gains for the aggregated groups of students participating in collaborative learning and other active learning, there is also research that shows that the particular composition of the collaborative learning groups can impact student outcomes. In a series of comprehensive comparisons of cross-gender learning and success, studies show that female groups appear to work simultaneously and produce better outcomes while members of the male community participate less and work in sequence (Sen, Ruta, Powell, & Ng, 2014). As a consequence, female groups take more advantage of the added advantages of collective learning than male groups (Sen et al., 2014). However, compared to same-gender groups, the participants of mixed-gender groups excel the most, greatly improving their commitment, concentration and the quality of group work (Sen et al., 2014).

2.5 Theoretical framing of the Proposed Study

My research adopts the framing of identity that comes from social identity theory (Stryker & Burke, 2000) and symbolic interactionism (Burke & Stets, 2009). Symbolic interactionism is the meaning that students develop as a part of social interaction in a setting, for example, a computationally intensive engineering semester. Based on social identity theory, when an individual holds an identity, they will act based on that acquired identity and align their action(s) with the community/social group they are participating in to achieve their goals. This framing of identity helps understand how identities are maintained and manifested in social interactions. This particular theoretical framing of identity has been adapted by researchers working in engineering identity, where Godwin et al. (2013) adapts social identity theory to describe group identities like gender, but role identity theory to describe taking on what it means to be an engineer.

This study is based on an established theoretical framework that has been utilized effectively in computer science education research for understanding computing identity (Mahadeo et al., 2020). For the current study, the operationalization of computational identity for research in engineering could provide a transition from one discipline (computing) to another (engineering) because of a similar skillset (programming) while also contributing to the engineering education body of knowledge.

In Figure 2, the disciplinary identity bubble includes the student's computational identity, and other discipline-based STEM and non-STEM identities within disciplinary identity are subcomponents of interest, competence, and recognition which help in identity formation and development. The personal identity bubble corresponds to the student's identified gender. The social identity bubble incorporates social interactions like group work interactions in the classroom as well as the group roles defined by the instructors which the student selects. All three bubbles of social, personal, and disciplinary identity overlap each other because identity development is a complex phenomenon and a person can possess multiple identities at a time. The research questions in section 2.6 are constructed based on this framework, which aims to understand the congruence of computational identity with other disciplinary identities or gender identity. Also, during the course which aspects of pedagogy and social interactions impact the computational identity development in students.

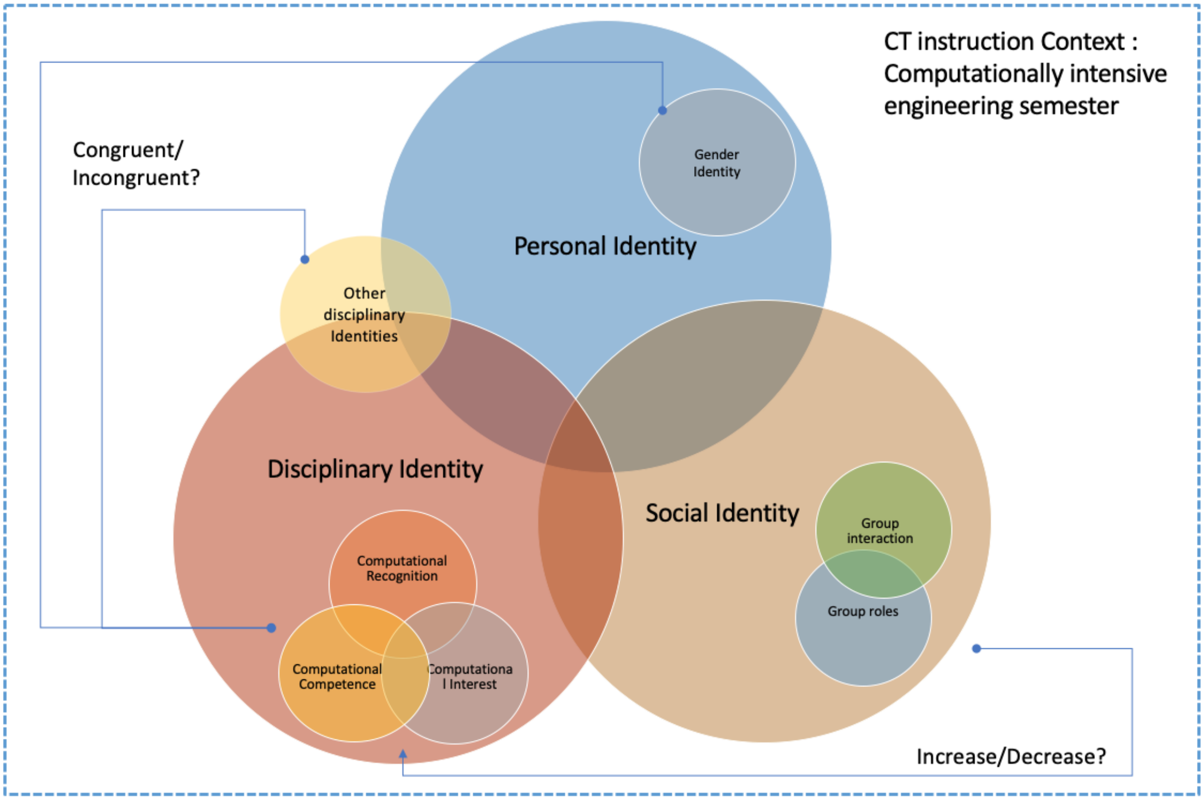


Figure 2. Theoretical framework to investigate computational identity

2.6 Research Questions

Research question 1: ***How do biomedical engineering and agricultural & biological engineering students describe their computational identity during a computationally intensive course?***

This work builds on a prior study of computing identity. However, Garcia and her colleagues have looked at computing identity by identifying three sub-constructs: interest in computation activities, perceived recognition as a computing person to perform computing-related activities, and perceived competence (Garcia et al., 2019; Mahadeo et al. 2020). The finding from this research question will help define a computational identity for engineering students through emergent themes found from student definitions that are then mapped to the framework presented in the Garcia et al. and Mahadeo et al. papers. It will help us understand if students describe having computational competence, recognition, and interest as related to having a computational identity Mahadeo et al. 2020 described in their research.

Research question ***2: In what ways computational identity is in congruence or in incongruence with other identities students hold?***

The literature talks about gender stereotypes in computing disciplines (Mendick & Francis, 2012; Peters & Pears, 2013) and antisocial nerd computing stereotypes (Wong, 2017) as possible causes or factors contributing to the underrepresentation of women in computing disciplines. When students see antisocial personalities as the dominant stereotype of a computational person, they start losing interest in or feeling like they do not belong. Computing discipline presents stereotypical characteristics, and both men and women who want acceptance in this masculine field adapt to these characteristics (Connell et al. 2015; Akpanudo et al., 2017). If someone sees a domain or role as congruent with self, they can develop an identity. When incongruence happens, it causes identity conflict that can lead to coping strategies to minimize one's identity in a particular context to create fit or to leave. The analysis relates participants' perceptions or views of his/her computational identity to their self-reported gender during sub-theme generation. Participants were asked an open-ended question of their perspectives on gender and BME/ABE becoming increasingly computational, so I study how the participants responded to that open-ended question, which would help me understand how participants relate computation to gender. The findings will provide insights into whether masculine identities and antisocial stereotypes are in congruence with a computational identity. Additionally, they describe having proficient skills and recognition in mathematics and engineering in congruence with computational identity.

Research question 3: ***What aspects of the course impact students' perceived competence to perform computational modeling and programming?***

The literature discusses how computational thinking-based instruction is beneficial to improving computational skills and capabilities. Computational competence improves with practicing computational skills. Secondly, pedagogical approaches in computer science education that de-emphasize prior coding skills and used group learning have shown increased persistence of women in computer science, most prominently at Harvey Mudd College (Dodds et al., 2012). Through active learning, students get to collaborate and participate in learning exercises. After a review of related literature, the practices like computational thinking-based instruction, engagement in computational activities, group work, and assignment of a role identity (technical leader) would lead to an increase in computational self-efficacy through competence in computational skills for developing computational identity. This question will be answered by identifying what aspects (e.g. taking a technical role or computational thinking-based instruction) are self-reported by participants which helped increase or decrease student's participation of perceived competence towards computational activities.

3. METHODS

In this chapter, I outline the methodology and research design used in this study. I describe the choice of methodology, IRB approval, study settings, and participants of the research study. I explain the data collection procedure, a description of the data analysis plan, limitations of the study, my role as a researcher, and the quality of the data collection and analysis process at the end.

To investigate the computational identity of undergraduate engineering students, this study is designed from a sociocultural theory of identity perspective and uses qualitative methods (Creswell, 2007) based on naturalistic inquiry (Lincoln and Guba, 1985) to pursue the research questions (in the following section) about identity development in the context of a semester-long course which is computationally intensive. A naturalistic inquiry is "research that focuses on how people behave when absorbed in genuine life experiences in natural settings" (Frey, Botan, & Kreps, 1999). This methodology helped with understanding the context-specific statements about the multiple, constructed realities of the participants.

Previously, the qualitative methodology has been used to understand identity development in several studies where the population is contextualized in university settings. For instance, Tonso (2006) examined engineering student identities and aimed to recognize engineers' unique student cultures through qualitative semi-structured interviews. Qualitative methodologies are often used in discipline-based identity research (Carlone, 2003; Anderson, 2007) because the lived experiences and internalized beliefs of identity are more easily accessed through interviews. For example, Carlone (2003) used ethnography to study the meanings of science and science students in a physics classroom in an upper-middle-class high school and the ways girls participated in science activities. A qualitative approach provides a robust way to study sociocultural interactions and it provides a way for participants to describe those interactions and experiences from their point of view. Additionally, researcher observation, in conjunction with interviews, can deeply examine unsaid issues of the sociocultural environment.

3.1 Research Questions

1. How do biomedical engineering and agricultural & biological engineering students describe their computational identity during a computationally intensive course?
2. In what ways computational identity is in congruence or in incongruence with other identities students hold?
3. What aspects of the course impact students' perceived competence to perform computational modeling and programming?

To address the above-mentioned research questions within a qualitative study research design, data were collected through the use of semi-structured interviews, direct observations, and surveys. In order to provide an in-depth picture of the study, contextual material from multiple sources was gathered. The following sections will describe the IRB approval, study setting, participants, data sources and data collection procedures, data analysis, limitations of the study, and my, the researcher's, role.

3.2 IRB

Data Collection approval was required from the Instructional Review Board (IRB) of the University, which was under the Human Research Protection Program with the purpose of overseeing research studies, recruiting, and protecting research participants. An online application for IRB approval, including survey questions, study description, audio interviews, was submitted on November 22, 2019. The IRB approval was received on December 9, 2019, which allowed us to conduct interviews and administer surveys for data collection beginning in January 2020. IRB approval can be viewed in Appendix A. A recruiting flyer, Appendix B was distributed to class participants specifying the purpose of this study, the contact information of the researcher, the conditions of their participation, and potential benefits for taking the survey.

3.3 Research Setting

Understanding the setting within which the students' experiences take place is integral to data collection and data analyses in qualitative research. In this study, the students' experiences pertain to their gender, project roles, and the computational identity they describe while participating in the course. It is important to understand the setting for this study at three different levels: (i) the physical and institutional setting, Purdue University, which is a public, land grant, Predominantly White Institution, with a large number of different engineering programs and a large number of engineering students, faculty, staff and (ii) the specific undergraduate thermodynamics course, Thermodynamics in Biological Systems II and (iii) the disciplinary departments associated with the course.

Purdue University is a public land-grant university funded by the state. The University offers undergraduate and graduate programs in more than 211 major fields of study and is well-known for its competitive engineering programs. Purdue University-Main Campus's enrolled student population is 59 percent White, 6.72 percent Asian, 4.75 percent Hispanic or Latino, and 3.03 percent Black or African American, according to 2017 estimates.

The course in question is situated between two engineering departments The Walden School of Biomedical Engineering and the School of Agricultural and Biological Engineering and is designed to teach fundamental introductory concepts of thermodynamics to students enrolled in both departments. The course is offered in the spring semester each year and approximately 120 undergraduate students enroll in the course. The course had recently been revised to include more computational modeling components, making the course more computationally intensive. This course used Jupyter Notebooks, an open-source web application that provides an interactive online environment for computing, and all computing exercises were in Python. The course syllabus is included in Appendix C, which includes course aims and objectives, as well as detailed content information.

The course had three major group projects. The projects were conducted before each significant exam where major exams were two midterms and one final. Each project had a major mathematical problem solving as well as a coding/programming component. Due to COVID-19, the instructors had to revise the second half of the course. To limit students' in-person interactions, the course content was shifted to an online medium, and project three was assigned as an individual activity as depicted in Figure 3.

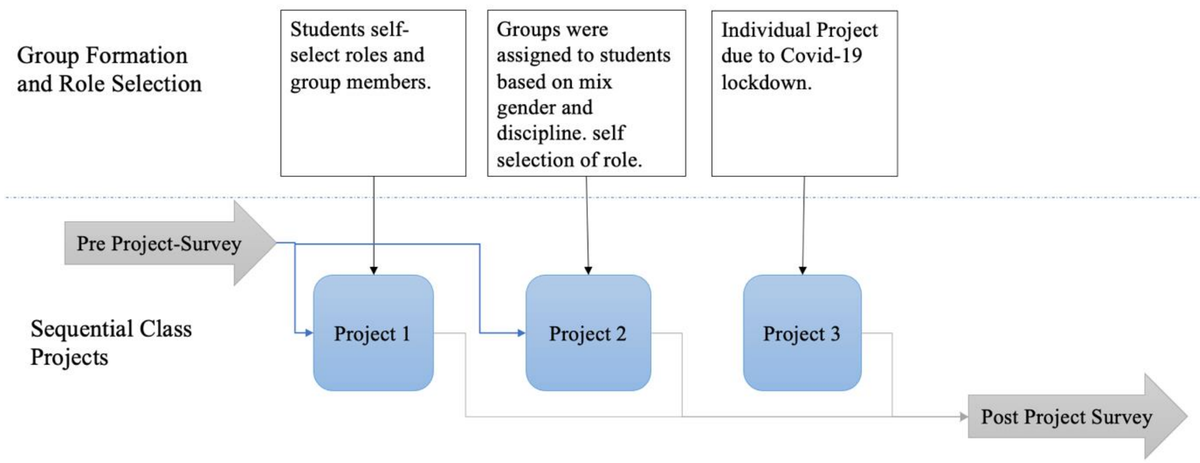


Figure 3. Data collection research design (Post Covid-19 Modifications)

The course was designed based on three specific enduring understanding elements for participants. They are based on what the participants should *know*, *do*, and *be* after completing the program. The three enduring understanding elements are outcomes that participants should: (1) know how to create computational artifacts based on the technical content of thermodynamics; (2) perform mathematical modeling and data analysis and test correctness of a computer program through programming; (3) be able to work together with others to reach an effective solution. These three enduring outcomes were achieved through providing an active learning-based class environment where students collaborated on programming-based projects in groups of 4 to 5 students.

In engineering disciplines, especially biological engineering, there is a critical need for engineering education practices to characterize the best practices for developing computational thinking in undergraduates because of the healthcare industry's growing demand for computational thinking skills. This thermodynamics class site was chosen for this study because engineering students who were not specifically computer engineering students participated in a highly computational thermodynamics class that demanded to program. The course also had 20% more women enrolled than men, unlike many other engineering courses. Additionally, the course instructors were also interested in understanding students' experiences in the course and how students developed computational modeling skills in the thermodynamics course.

Coming from engineering education, I was an outsider to the biomedical engineering and biological and agricultural engineering departments. At the same time, I was also familiar with thermodynamics concepts and programming because of my educational background in sciences and computer engineering.

3.4 Research participants

One hundred fourteen students were enrolled in the thermodynamics class when the course started, and these 114 students were given the opportunity to respond to the surveys and participate in the semi-structured interviews. The students are all sophomores, most likely second semester sophomores. The students were between 18 to 21 years of age. The students who were enrolled in the thermodynamics class were either studying agricultural/biological engineering or studying biomedical engineering at Purdue University. For this study, a total of 23 students were interviewed once during the semester-long thermodynamics course. Nine students participated from agricultural and biological engineering and fourteen students from biomedical engineering. The detail of interview participants is provided in Table 1 under section 3.4.2.

3.5 Data Collection

The data used for this study comes from data collected as part of the NSF awarded research study called Computational Thinking In Biological Engineering under Grant No.1830802. The NSF project had three objectives:

1. To characterize the progression of computational thinking in undergraduate biomedical engineering students from novice to expert over three courses offered at Purdue University.
2. To examine the intersection between gender, engineering identity, and computational thinking.
3. To iteratively improve the undergraduate curricula to promote growth in computational thinking for all Bioengineers.

Even though this dissertation utilizes data collected as part of the NSF project, this dissertation focuses on investigating computational identity in tandem with gender and other discipline-based identities. The NSF project focuses on engineering identity and challenges of computational thinking pedagogy while this dissertation study seeks to understand the biological engineering students' computational identity. The focus on investigating computational identity was explored after I studied and researched on the topic of engineering identity development and spent a year working on the second objective of the NSF project.

Table 1. Data Collection Activities During the Semester

Spring 2020	Timing/Weeks	Data Collection Activities		
Week 1	13 – 17th January	Quantitative Survey – Pre-Computational Self-efficacy	Identity and Computational Interviews	Weekly classroom observations (held before midterm)
Week 2	20 – 24th January	Project 1 – Dinosaur Project Pre survey – students will self-select roles		
Week 3	27 – 31st January			
Week 4	3 – 7th February	Post Project survey		
Week 5	10 – 14th February	Project 2 – Toxin Receptor Project Pre survey – students will self-select roles but juggle within groups		
Week 6	17 – 21st February	Post Project survey		
Week 7	24 – 28th February			
Week 8	2 – 6th March	Midterm Week		
Week 9	9 – 13th March	Project 3 – Multi Stable States Project Pre survey – group formation for project 3 and 4will be decided in a meeting post project 2		
Week 10	16 – 20th March	Spring Break		
Week 11	23 – 27th March	Post Project survey		
Week 12	30 – 3rd April			
Week 13	6 – 10th April	Project 4 – Reaction diffusion System Project		
Week 14	13 – 17th April			
Week 15	20 -24th April	Post Project survey		
Week 16	27 – 1st May	Quantitative Survey- Post Computational Self-efficacy		

3.5.1 Changes in Data Collection Due to COVID-19

The data collection for this study was being conducted in Spring 2020 when the Covid-19 virus spread across the globe. In March 2020 the university implemented social distancing measures and protocols limiting the number of people who could be co-located. In person campus classes were canceled and shifted online. The semi structured interviews conducted during the social distancing phase were conducted online through video conferencing software. Seven out of twenty-three interviews were conducted online during the months of March and April. The classroom observations were only conducted prior to the midterm exam because the class sessions were shifted to online modules after mid-March. Pre-project surveys for projects three and four were canceled, and project four was converted into a final exam deliverable.

3.5.2 Direct Classroom Observations

Qualitative researchers use direct observation as a form of data collection. Data collected during direct observation of participants may include information regarding the surroundings and even background noise (Denzin, 2009). When using participant-observation as a qualitative research method, the researcher enters the world of the people they wish to study (Taylor & Bogdan, 1998; Wolcott, 2008). The degree of participation in addition to observation varied. As an observer, I had opportunities to participate in the activities of students I was observing in some situations. At times I had to switch from active participant to passive observer on the "participant/observer continuum" (Bogdan & Biklen, 2007). Because of the setting's limitations and structure that the students taking the thermodynamics course were registered in varying courses which were held in different buildings across campus, I was a full-time observer and hardly participated in the activities other than attending the lectures. I observed each in-person class session held before the course was shifted online because of the COVID-19 pandemic but did not observe the online class sessions. As a replacement for online class sessions, the students were given the flexibility to watch the instructor's weekly content videos without being limited be a fixed class time. The class observations were not audio- or video-recorded. During each classroom observation session, I recorded observation notes using Microsoft Word on a laptop.

I constructed an observation protocol (see Appendix D) to assist me in the observation process. In my direct classroom observations, I focused on the following things:

- Topic of study and type of activity in each class session.
- Breakup of the class time into lecture, and active learning discussions/problem solving session.
- Gender composition of each group.
- Student interactions while they engaged in interactive discussions/problem solving which helped me observe the interview participants in classroom settings.
- Visual documentation (i.e. sketches and pictures of classroom setting)

3.5.3 Semi Structured Interviews

Interviewing is a standard mode of inquiry in qualitative research. The most frequent form of interview is the person-to-person encounter in which one person elicits information from another (Merriam, 2009). "At the very heart of what it means to be human is the ability of people to symbolize their experience through language" (Seidman, 2006, pp. 9). Interviews obtain data that reflect behavior, attitudes, and experiences while the interviewer is not present. I chose to interview the participants of my qualitative investigation because I wished to know about thoughts, feelings, and experiences that were not observable to construct meaning (Seidman, 2006). I recruited participants from the class sessions. I introduced myself, explained my purpose, and clarified that I had no involvement in course grading. I requested an interview to take place at the time and location of the participant's choosing. A total of 16 interviews took place on the university campus in locations used explicitly for face-to-face interviews, whereas 7 interviews were conducted online. These locations were present in buildings of biomedical engineering as well as engineering education.

The subconstructs from computing identity and social identity theory were primarily used to develop the interview protocol for the study. This study's context is a computationally intensive engineering classroom, where identification with a computational identity is one small part of an engineering student's identity. This framework divides the undergraduate student’s identity space into three areas (personal, social, and disciplinary) in the context of a computationally intensive thermodynamics classroom.

I constructed a semi-structured interview protocol (see Appendix E) to assist me in the interviewing process. The interview protocol was designed using broad questions to allow ample detail and a variety of answers without guiding the participant to a particular response. The semi-structured interview protocol contained a mix of more- and less-structured questions. At some points in the interview, I asked the interviewee to respond to a particular statement or define a particular concept or term, following which I asked less structured questions designed to elicit each respondent's unique perspective on the topic. The questions used are open-ended and flexible. The interview was guided by my interest in a particular topic and subsequent subtopics. Flexibility in the interview process allowed me to explore the respondent's perceptions and follow-up on new ideas as they are presented by the respondent (Seidman, 2006). The unstructured or informal mode of interviewing was more like a conversation on a particular topic. Merriam (2009) suggested that even in a predominantly semi-structured interview, some time spent in an unstructured mode can allow the respondent to raise subtopics that the interviewer may not have considered and add fresh insights related to the interviewer’s topic of interest.

I asked students questions based on the discipline-based identity (computing identity) framework (Garcia et al., 2019). Students were asked questions related to recognition, self-perception, competence, performance, and interest. I also allowed the interviewed students to share any other thoughts they might have on the topic and tried to engage the interviewees in a conversation about and around the subject. Each interview lasted between 40 to 65 minutes. While conducting the interview I wrote memos which had participants' pronouns, participants' description (what was the participant wearing, a brief geographical description of where the participant was born and resided, the participant’s age, how the participant was recruited, if the participant was an agricultural engineering, biological engineering, or biomedical engineering student), the actual and preferred pseudonyms provided by the participants, and interesting points of observation during the interview with time stamps. Examples of "interesting points of observation" include excerpts where students discussed gendered experiences in engineering without being prompted.

Student/Interviewee actual name, university email address, and demographic information, and audio responses were kept confidential and the audio recordings were transcribed immediately to protect participants' confidentiality. I transcribed the audio recordings of the interviews within 24 to 48 hours of conducting the interviews. When transcriptions were completed, l went through the recordings again to check against the transcriptions. I conducted seven interviews online on Zoom video conferencing software due to the COVID-19 pandemic when in-person classes were shifted online. These interviews conducted via Zoom followed the same protocol as the in-person interviews. They were conducted on video but were only audio-recorded as the IRB protocol for the study did not include video recordings as an approved data source.

To de-identify interview transcriptions, participants' real names were replaced by the interviewee’s self-selected pseudonyms (see Table 1). Students were told about the confidentially of the audio recorded data before they began the interview. After the interview was completed, students signed a human subjects log, which had the student's actual name, duration of the audio recorded interview, and compensation amount of $15 (the amount approved by the university institutional review board per interview)

Table 2. Interview Participants

Sr No	**Pseudonym**	**Pronouns**	**Engineering Discipline**
1	Bryn	She/Her/Hers	BME
2	Sarah	She/Her/Hers	BME
3	Uma	She/Her/Hers	BME
4	Neetu	She/Her/Hers	BME
5	Mary	She/Her/Hers	BME
6	Lisa	She/Her/Hers	BME
7	Anne	She/Her/Hers	BME
8	Annalise	She/Her/Hers	BME
9	Maggie	She/Her/Hers	BME
10	Victoria	She/Her/Hers	BME
11	Amira	She/Her/Hers	ABE
12	Meghna	She/Her/Hers	ABE
13	Emma	She/Her/Hers	ABE
14	Amelia	She/Her/Hers	ABE
15	Jessica	She/Her/Hers	ABE
16	Anna	She/Her/Hers	ABE
17	Kate	She/Her/Hers	ABE
18	Thomas	He/Him/His	BME
19	Osama	He/Him/His	BME
20	Jim	He/Him/His	BME
21	Fazal	He/Him/His	BME
22	John	He/Him/His	BME
23	Peter	He/Him/His	ABE

3.5.4 Surveys

Surveys were a part of the broader NSF project, and limited information regarding participants' project role and computational self-efficacy was used to complement the analysis of the interview data. A total of seven surveys were administered during the semester (see Table 1). Initially, the course design included four group projects. Due to the new university policies of social distancing in mid-March two of the projects that were supposed to be carried out as team projects were converted into individual projects and a take home final exam. The pre and post course survey instrument was designed and developed by leveraging items engineering self-efficacy survey (Mamaril, Usher, Economy, & Kennedy, 2016). Two pre project surveys (see Appendix F) were administered before the start of the group projects, and one combined (pre and post-project) survey was issued after the individual project. The pre project survey asked the students to rank their preferred project roles and list learning goals they aim to achieve after completion of the project. The time to complete the survey was 10 minutes on average. The surveys were designed and administered using an online survey platform (Qualtrics). Each survey was active/open for one week. The survey was only accessible through an anonymous survey link distributed to the students during class through the learning management system. In this study, only the pre-project survey from two group projects and one post-project survey conducted after individual projects are used for analysis purposes where participants were asked about their project role, and computational modelling comfort level.

3.6 Data Analysis

3.6.1 Interview data analysis

Interpretation of the interview data began simultaneously with data collection (Hatch, 2002). The interview data analysis continued with the review of each transcript before member-checking. During member-checking transcripts and resultant themes were shown to participants to check for accuracy and resonance with their experiences. The coding of transcripts was supported by MaxQDA 2020 (VERBI Software, 2019) for data analysis. MaxQDA provided an organized storage system, and the data files could be readily accessed. The units of data were located easily, whether it was an idea, a statement, a phrase, or a word with a data file, it also gave the flexibility to code each unit of data with an unlimited number of codes so that data can be retrieved and organized in any number of patterns and themes. The analysis for the initial codebook construction began with selecting a sample of three interviews chosen to represent a rich and diverse set of participants' data, which had been collected across the course of the data collection process. The criteria for the selection of these initial three participant interviews and subsequent interviews selected were:

- Researcher's judgment of the richness of the interview.
- Difference in computational experiences.
- Early (week 2), middle (week 8), and late participation (week 16) in the interview during the semester (one interview was selected from each phase to construct the initial codebook).
- Gender variation.

Identification of connections to theoretical framework constructs and sub-constructs through initial codebook generation was made during round one coding. A line-by-line analysis of participant transcripts (Smith, 2009, pp. 79) was performed where the code assignment was inductive as well as deductive based on the theoretical framework. This phase consisted of at least two passes through each transcript, each time focusing on a different form of coding as deductive (based on the theoretical framework) and inductive (in vivo). Deductive coding meant coding for constructs and sub-constructs based on the theoretical framework in each of the participant's sentences. In vivo coding used participants' words from participants' sentences as codes. Then, axial coding was used for theming the data. Axial coding was used as a second-round coding technique. Axial coding helped to combine related codes found during first cycle coding via inductive and deductive thinking, which was necessary for drawing novel understanding. An excerpt of a codebook with two coding levels where initial and secondary coding included (deductive and inductive coding) is provided in Appendix G.

3.6.2 Coding Observation Notes

Seventeen class sessions were observed in person. It was observed how many groups in each class session were homogeneous versus mixed gendered. Although this breakdown was quantitative, group formation observations were utilized in the follow-up questions of the semi-structured interviews conducted with participants who volunteered for interviews. Triangulating observation notes with participant quotes is a suitable way to understand objective reality (Carter, 2014). While coding the observation notes, I considered the list of questions recommended by (Emerson, 2011, pp. 77), regardless of research purpose:

- What are people doing? What are they trying to accomplish?
- How, exactly, do they do this? What specific means and/or strategies do they use?
- How do members talk about, characterize, and understand what is going on?
- What do I see going on here?
- How is what is going on here similar to, or different from, other incidents or events recorded elsewhere in the fieldnotes?

3.6.3 Survey Data

Qualitative and quantitative data was gathered through surveys during the course of the semester. The quantitative data in the survey were analyzed to complement the qualitative findings in-depth regarding the 23 participants who participated in the study. I specifically focused on:

- Change in computational modeling self-efficacy during the course. (Pre and post-project surveys)
- Student role assignments (Post-project surveys)

Because the study focuses on answering three research questions using multiple data sources a table (Table 3) was constructed to depict alignment between the research questions, data sources, and data analysis produce based on the sources. Additionally, another table was developed (Table 4) to connect the computational identity development framework (Mahadeo et al., 2020) with the data sources.

Table 3. Alignment between research questions, data collection, and data analysis.

Research Questions	**Data Sources**	**Data Analysis Procedure**
1. How do biomedical engineering and agricultural & biological engineering students describe their computational identity during a computationally intensive course?	40-65-minute semi-structured interviews on Identity, group work, computation, recognition, and persistence.	Round One: In vivo (constructing computational identity code books), deductive and inductive coding for codes related to computational person, recognition, interest, and competence. Round Two: Axial coding to generate themes among data.
2. In what ways computational identity is in congruence or in incongruence with other identities students hold?	a) 40-65-minute semi-structured interviews on Identity, group work, computation, recognition, and persistence. b) Pre course survey for understanding technical vs non-technical role preference among participants.	Round One: In vivo (constructing code books), and inductive as well as deductive coding with respect to constructs like recognition, interest, lived experiences, disciplinary identities, and gender. Round Two: Axial coding to generate themes among data. Women preference for technical vs non-technical role was observed through descriptive statistics.
3. What aspects of the course impact students' perceived competence to perform computational modeling and programming?	a) Semi-structured interviews b) Likert Scale Survey Response to level of comfort in performing computational modeling activities	Round One: In vivo (constructing code books), and deductive coding with respect to constructs (recognition, technical role preference or allocation, Interest, lived experiences, competence, confidence, and persistence) Round Two: Axial coding to generate themes among data. Analyze the increase/decrease of each participant’s computational modelling and programming self-efficacy between the first and last project through sanky plot visualization.

Table 4. Data sources to analyze computational identity development

Identity Development Constructs	Data Sources
Competence	• Pre-Project Survey (Likert response question on personal comfort level with computational modelling) • Semi-structured Interviews (codes related to competence in computational modelling or programming)
Interest	• Semi-structured Interviews (codes related to interest development in computational activities)
Recognition	• Pre-Project Survey (Likert response question on personal comfort level with computational modelling) • Semi-structured Interviews (codes related to recognizing one's own self or others as computationally proficient)

3.7 Quality/Trustworthiness of Data Collection and Analysis

3.7.1 Trustworthiness

Qualitative data should be dealt with the same cogency as quantitative data. It is the quality of process rather than the quality of the final product that matters in interpretive research, according to Walter et al. (2013). I draw on the framework of interpretive research by (Walther, Sochacka, & Kellam, 2013) during the data collection and handling process. Theoretical, Procedural, Pragmatic, and Communicative Validation, alongside Process Reliability, were a focus during the data collection and analysis phase of the study as described in Table 5.

Table 5. Considerations of Quality (Walther, Sochacka, & Kellam, 2013)

Quality Aspect	Making Data	Handling Data
Theoretical validity	Captured breadth and variation of experiences by interviewing students. Student's self-volunteered for interviews from a variety of genders, class groups, etc.	Represented variation in the participant sample while analyzing data and reporting findings.
Procedural validity	Comprehensively capture participant experience during semi-structured interviews with open-ended questions for clarity.	Situated analysis in participant's context. Reflexivity/transparency of researcher's own perspectives
Pragmatic validity	Open-ended non-leading questions asked were asked based on constructs from the framework.	Present results to project researchers and course instructors through detailed discussion of findings.
Communicative validity	An authentic connection was developed between interviewer and interviewees when interviewees shared lived experiences as a response to interview questions.	Discussing findings with members of the research project team and representatives of the sample during analysis.
Process reliability	Data was collected and recorded in a dependable way through a data collection procedure where the data was recorded in an audio recorder and transcribed with 48 hours of interview by the transcriber. Reflexive documentation.	Procedures for generating and representing knowledge are documented by following the protocols for data collection and analysis.

Ethical issues were also considered at every step of the research process. This was not just about obtaining ethical approval for a study but also ensuring the rights of participants were not violated. When reporting qualitative research, participants' anonymity and confidentiality were not breached by using pseudonyms and deleting the audio files after transcription, any identifying information in the transcripts was also removed.

3.7.2 Qualitative Coding Consensus

Coding consensus was performed on four summaries of data (exempts) each of which were 2-3 pages in length with another qualitative researcher that captured the essence of what was said with greater clarity within the topics used to segment the interview data. Later, two independent coders who had expertise in qualitative research were given exempts of coded data with corresponding themes. We compared our codes and discussed any discrepancies until consensus was reached.

3.7.3 Triangulation

There are four types of triangulation: the use of multiple methods, multiple data sources, multiple investigators, or multiple theories to confirm emerging findings (Merriam, 2009). This study uses multiple methods of data collection and multiple sources of data: interviews, observations, and surveys. I checked the information that I gathered from my interviews against my observations and survey results. The class observations informed the interviews and follow up questions as well as my synthesis of the study findings.

4. FINDINGS

Through the use of a qualitative research methods design, using the framework developed in Chapter 2 based on social identity (Stryker & Burke, 2000) and computing identity (Mahadeo, 2020), this study sought to answer the following research questions:

1. How do biomedical engineering and agricultural & biological engineering students describe their computational identity during a computationally intensive course?
2. In what ways computational identity is in congruence or incongruence with other identities students hold?
3. What aspects of the course impact students' perceived competence to perform computational modeling and programming?

The findings of this study are organized into three sections based on the research questions. Section one, "Computational Identity," presents the themes on the first research question "How do biomedical engineering and agricultural & biological engineering students describe their computational identity during a computationally intensive course?". Section two, "Congruence between computational identity and other identities," presents the findings pertain to the second research question, "In what ways was computational identity in congruence or dis-congruence with other identities students hold?” Section three, "Instructional practices to support computational identity development," explains the findings related to the third research question "What aspects of the course impact students' confidence to perform computational modeling and programming?"

4.1 Computational identity

4.1.1 Who is a computational person?

During the interview, I asked the participants about their definition of a computational person, followed by if they see themselves as this computational person or not. In situations where the participants answered yes or no, I asked them why they felt that way. In cases where they reported partial or moderate self-identification as a computational person, I asked the participants what will make them feel more like a computational person. It is important to understand how students define a computational person to understand what skills, abilities, and ways of thinking of a computational person emerge from student explanations, it allowed me to investigate if there are any gender or antisocial stereotypes associated with the emergent defining themes. Thematic analysis was performed on student responses to the question, "Who is a computational person?" to find the emergent themes based on student definitions. The students not only defined a computational person as having particular kinds of skills, but also discuss various skills as well as knowledge, abilities, and orientations to learning in order to be a computational person. In the proceeding section, the themes correspond to how students define a computational person.

Theme One: Participants perceived a computational person to be proficient in mathematics, programming, and problem-solving knowledge.

The first emergent theme refers to the skills, abilities, and ways of thinking a computational person possesses. Eighteen interview participants described a computational person as having mathematical, computer programming, and problem-solving skills, abilities, and ways of thinking. Participants explained that a computational person possesses the ability to critically think through problems that are mathematical problem solving based Having these skill sets corresponds to having skills and capabilities in order to have a computational identity.

For example, Jim (BME) started with defining a computational person as someone who has enough competence in mathematics, logic, and programming: "Well if I was to define a very computational person, that is like dealing with numbers, or dealing with logic.... If they are competent enough with obviously numbers, math, programming, that sort of thing." In this example, Jim initially talked about a computational person in terms of the types of things a computational person does "dealing with numbers or dealing with logic," but Jim then shifted from the things a computational person does, to a computational person's competence or proficiency.

In contrast to Jim's definition, Kate (ABE) did not include the type of things a computational person does; instead, she focused on the set of skills and proficiencies she associated with a computational person. Kate started describing a computational person based on mathematical skills set followed by programming proficiency. She said, "I would say computational person is somebody who is probably good at math and by being good at math they are probably good at logic and they are very focused on getting the calculations right. Are probably very detailed oriented. There is mathematics and programming. I would say a computational person is like a logical, they know how to work with like different technologies, and they are kind of like the phrase 'techie'" (Kate). Kate identified a set of skills related to math and working with technology, as well as abilities like 'logical thinking' and 'attention to detail'. Interestingly Kate, herself viewed skills like logic and mathematics as inherently connected, as she noted "being good at math [suggests that a person] is probably good at logic." (Kate)

Similar to Kate, Lisa (ABE) also focused on skills and abilities without being prompted to express her views on skills and abilities. Lisa, like Kate, identified mathematical skills as a core part of a computational person she was interested in mathematics which derived her to define a computational person as having an interest in mathematics, "I have always enjoyed math and I think I am a strong student in mathematics, but I think I am only like the tip of the iceberg with computational problems." (Lisa) As she continued, she focused on the practical application of these skills in a problem-solving capacity,

> I would think a computational person is someone who, not only succeeds in mathematical problem-solving type problems, but also someone who applies that to like their everyday life or other problems that they are solving. Someone who thinks more with numbers and going through that process, that is how I would describe a computational person. (Lisa)

For Lisa, a computational person is not only proficient in certain skills like mathematics, and problem solving but also possesses the ability to apply these skills in daily life.

Similarly, Anne also focused on applications of computational skills, including programming as well as mathematics, in any field the computational person is working in, *"I think a computational person is just someone who in their field, whatever it may be, uses math or coding or some sort of that kind of setting to work on their stuff*" (Anne). This description indicated that Anne believed that a computational person applies computational skills like mathematics and programming in all fields of work.

For most of the interview participants, a computational person is someone who has mathematical, computer programming, and problem-solving skills. Some of the participants recognized this as a combination of the things a computational person does as well as the competencies they have; others recognized relationships between these skill sets and also recognized associated skills and attributes, like being detail-oriented and being good at logical thinking. Several students also described having the ability to apply these skills to daily life and other fields of study.

Based on the computational identity framework, three primary subconstructs that contribute to the development of a computing identity are belief in one's performance/competence, interest, and recognition in computing. Students were not prompted to define a computational person through skills or abilities, yet they defined a computational person through the performance/competence subconstruct by explaining which skills the computational person performs and excels at and in one case also the interests of a computational person. Participants discussed not only have skills but also abilities and ways of thinking. This finding aligns with the trait-based stereotypes in STEM, e.g., STEM is for geniuses (Starr, 2018). However, while defining a computational person, participants did not express how the computational person was recognized by others. This finding was found to be in alliance with Mahadeo and colleague's (2020) work that competence is an essential component of computational identity development and also provided insight into the specific abilities and skills associated with the competence of a computational person. However, it was not consistent with Mahadeo and colleague's (2020) work on the aspect that students did not talk about how a computational person is recognized.

Theme Two: A computational person possesses an ability to make decisions about their computational work

The second emergent theme found from participant explanations was that they saw a computational person as someone who considers possible outcomes and consequences in the process of making decisions. Participants directly addressed that a computational person has the ability to make decisions. Uma, Jim, and Osama reported detail on why a computational person would have the competence of decision making.

Uma (BME) connected the "logical" decision making of computational people with the practice of programming,

> I would describe a computational person as someone who thinks very technically, someone who looks at the consequences of like what they do, like thinking ahead. because when you are coding you have to always think about like if I do this, what will happen then? That's what I think of when I think of a computational person. (Uma)

For Uma, the ability to think ahead gives a computational person the ability to make an appropriate decision by anticipation.

Jim (BME) gave a fuller explanation on similar notes as of Uma about a computational person's decision-making skills. According to him a computational person makes decisions.

> a computational person has ability of decision making based on weighing pros and cons of different decisions and then going with the least damaging decision I guess when I think of a computational person, I think of someone who I wouldn't say just think things through, but like think things logically and when it comes to making decisions, they weigh their options in a logical way as sort of like statistical way. Like for me it's like if I was to make a decision, I would think, Like, Oh, there is 75% chance this decision will go wrong and we don't want that happening, so I am going to take the other option, which might be 30% failure sort of thing as compared to 75%. That's specifically decision making. (Jim)

For Jim, a computational person predicts future outcomes based on weighting pros and cons, weighing options, and then estimating the likelihood of failure in the context of decision making.

Osama (BME) like Jim and Uma mentioned decision making skills as a key part of what it meant to be a computational person. He added that a computational person would not only be able to do logical decision making but would also be efficient in making them, "In terms of skills I think computational person would be good with logic and decision making but also someone who is very efficient you know." For Osama, efficient decision making was a crucial competence for a computational person.

For these interview participants, a computational person is someone who have skills of decision making. The participants shared a belief that the ability to make decisions informed by computational work is essential to be computational identity, which is connected to the theoretical framework through the competence component where competence in this particular case is the ability to succeed in computational work by using the skill of decision making. The students adhered to ideology that believes in a logical, objective, and rational decision making by the computational person and the viewed the computational skills with the context of the ideology. All the students who described this "logical" decision-making process in computational people, made positive value judgements. They considered this to be essential to "good decision-making" indicating that all of these students had been socialized into computational ways of thinking even if they had differing levels of self-identification as a computational person.

Theme Three: Translate natural language to code (through pattern recognition and/or decomposition)

Five participants outlined in detail that a computational person can translate a natural language problem to a computer program. In their definitions of a computational person, Maggie, Annalise, and Neetu emphasized having the capacity to translate between language and computer programs are essential to a computational person.

Maggie (ABE) explained that a computational person has the ability to translate and interpret raw data to formal programming language.

> I think computational is a lot of taking something that is raw data and making a pattern out of it so that you can perform, or you can like find a conclusion for it. So, either like through a model or through math or something computational and it spits out a pattern and then you can conclude something based on that pattern (Maggie).

Being computational for her is to convert raw data into a pattern and then converting that pattern into computer recognizable language in order to produce the desired results.

Similar to Maggie, Annalise (ABE) described a computational person as someone who is comfortable translating from a human spoken language to a programming language.

> I would say a computation person is someone who can look at a problem and see how it can be translated into like a programming in a programming sense and is comfortable with programming and computation in a way that they do not get intimidated by computational problems, they can approach it.(Annalise)

For Annalise, a computational person not only has the skills and ability to translate but also is comfortable and at ease with converting the natural language into a program.

Neetu (BME) also talked about having the ability to translate between natural language and programming. She explained that a computational person performs this translation by keeping the perspective of the machine in sight by understanding how the natural language can be decomposed for the machine.

> Generally, a computational person to me is someone who can look at a problem and understand how to phrase it so that a computer could understand it. Can you look at a problem? And see, okay, here is how I need break it down. Here's all the pieces I need to take apart. Here are the parts that need to become loops. Here are the parts I need to define. And this is how I am going to lay it out. Someone who knows how do you do that? Versus like someone who cannot do that, is the basis of a computational person to me. (Neetu)

For Neetu having the competence to decompose and then lay the decomposed pieces into a translatable pattern for computer programming is essential to a computational person.

For some of the interview participants, a computational person is someone who can translate between raw data or language and computer understandable language. Some of these participants mentioned having this particular skill whereas others described additional abilities associated with translation between these languages as being comfortable and knowing how to decompose as well as recognize a pattern, which is connected to the competence construct of computational identity development. Because competence is the self-belief to succeed at performing a specific task or skill, when a student belief that they have the skill to recognize patterns in computer programs or algorithms they feel they are competent at pattern recognition.

Theme Four: A computational person can encompass multiple and possibly heterogeneous viewpoints, and representations.

Four participants envisioned a computational person as having multiple perspectives on analyzing problems and representing the solutions. The participants reported that a computational person thinks from multiple perspectives. The computational person keeps the personal biases out of the equation. For example, the computational person will not immediately jump to the commonly accepted conclusions.

Mary (ABE) explained a computational person would like to understand all the aspects of the problem which lead to a solution or a decision.

> I think a computational person always has to like understand, not only understand, but like have like the step by step process of how you got to the answer, which like in BME is sometimes hard because you will learn in biology and the instructors will be like, okay, this is why this is true, but it's outside of the scope of class, like outside the scope of this specific course. So, you just need to know that this is true. And like a computational person would probably, struggle with that because they would want to like go back and be like, okay, well, why is that true? They are curious and they would want to know why? And they would not take everything at face value. They would want to go back and be able to trace why something is the way it is. (Mary)

Mary talked about the processes explained above that the multiple levels pertain to multiple aspects of problem-solving process.

Sarah (ABE) added another dimension of having a logical process to looking at a problem from multiple perspectives. She explained a computational person is “Someone that can think on multiple levels, how they connect, but it is not like it is just a free response almost in a way. Like, there is logic to the process that they are working with." For Sarah, a computational person looks at how different components connect together and for doing this they follow a procedure.

Anna (BME) gave similar comments to Sarah. She explained that a computational person would take into consideration multiple perspectives before proposing a solution, "Someone who is computational likes to look at a situation from many aspects and make sure they are answering it in the best way possible. I think someone who is computational would pay attention to detail." According to her, a computational person will be detailed oriented to look at a problem from multiple perspectives and will consider the best possible way to represent the proposed solution.

Some other participants also touched on the same subject while defining a computational person. They mentioned that the computational person possesses the ability to have a broader perspective towards problem understanding and problem solving. The broader perspective comes through considering multiple perspectives towards problem solving and if all the parts of a solution connect at a broader level. Similar to previous themes in this section about how students defined a computational person, the current theme also pertains to the competence construct from the computational identity development framework (Mahadeo et al, 2020).

4.1.2 My computational identity is in the making

The next subsection pertains to how students described their own computational identity or related themselves to the computational person they talked about. The participants were asked an open-ended question if they see themselves as the computational person they just described. Participants gave a yes, no, or partially/moderately response to this question with a justification of the response. Participants were then sorted based on the yes, no, or partially/moderately response to understand in detail how students describe their own computational identity (see Table 6).

It was no surprise that 16 of the 23 interview participants responded that they partially or moderately felt that they were a computational person because the definition of a computational person was complex and involved having many skills, traits, abilities, and ways of thinking. Students felt that they had the necessary skills essential to this identity (i.e., logic, programming, or computational modeling); however, they felt that they were still working on developing other aspects essential to seeing themselves as a computational person.

Table 6. Interview Participants

Sr No	Pseudonym	Pronouns	Engineering Discipline	Adherence to Computational Identity – based on interview responses
1	Bryn	She/Her/Hers	BME	No
2	Sarah	She/Her/Hers	BME	In the making
3	Uma	She/Her/Hers	BME	Yes
4	Neetu	She/Her/Hers	BME	In the making (more as no)
5	Mary	She/Her/Hers	BME	In the making
6	Lisa	She/Her/Hers	BME	In the making
7	Anne	She/Her/Hers	BME	Yes
8	Annalise	She/Her/Hers	BME	In the making (grown with time)
9	Maggie	She/Her/Hers	BME	Yes
10	Victoria	She/Her/Hers	BME	Moderately
11	Amira	She/Her/Hers	ABE	In the making
12	Meghna	She/Her/Hers	ABE	Yes
13	Emma	She/Her/Hers	ABE	Moderately
14	Amelia	She/Her/Hers	ABE	In the making
15	Jessica	She/Her/Hers	ABE	Yes
16	Anna	She/Her/Hers	ABE	Yes
17	Kate	She/Her/Hers	ABE	Moderately
18	Thomas	He/Him/His	BME	Moderately
19	Osama	He/Him/His	BME	Moderately
20	Jim	He/Him/His	BME	Moderately
21	Fazal	He/Him/His	BME	Yes
22	John	He/Him/His	BME	In the making
23	Peter	He/Him/His	ABE	In the making

In the final column, Yes means strong adherence, no means strong defiance, and Moderately/In the making means the adherence is in development adherence phase

Below, I examine students' discussions of their computational identity by gender.

Men's self-perception of computational identity

A number of men reported that they are proficient computer programmers and very comfortable in performing computational activities, but these connections did not always result in a strong adherence to a computational identity. Thomas (BME) started coding early in life and joined the Purdue university in the department of computer science and engineering and later switched to BME. He had a decade long programming experience and also showed a passion for programming because he taught a programming course earlier. When I asked him if he felt like he was a computational person or not he replied by saying,

> Yes and no. I am good at coding and I like it…. But the thing is I am not very detail oriented and my issue is that I cannot be because I am so ADHD, skip around, I tend to miss the small details. (Thomas)

Even though he had skills associated with the computational person we were talking about why he was adhering to the computational identity only partially.

Another student John (BME) had previous extensive experience in programming and joined Purdue university in the department of computer science and engineering and later switched to biomedical engineering. Like Thomas, John adheres to the computational identity partially. He believed that a computational person is very planned and logical. He explained to me why he felt that he has this partial identity.

> I don't really walk into something with a definite plan. I am kind of a person who have plans but also half kind of wings. It improves my way through life. So, I think that's like a different approach because mine is more half and half and there's this more like wholly based on just step by step and logical. (John)

Jim (BME) had proficient programming skills (according to his project group members) and based on classroom observations. He expressed about the computational identity that he does not fully adhere to this type of identity because

> sure, I can do math, I can see things through math, but I think things are not necessarily in mathematical terms. I see things in like visually, sort of thing. I just see how things work and then the math is just the property of it. So, say if I am looking at a physics problem, right? I don't think of the math whenever, say for like a problem. But I am not thinking of it in a mathematical perspective. I am just thinking what makes sense. Like I can see and how it applies too, if I'm thinking like from what I have experienced in the real world. (Jim)

Jim thinks someone with computational identity will only think in a mathematical perspective.

Peter (ABE) was confident being a competent enough person when it comes to computational skills. When asked about if he adheres to a computational identity, he went by answering

> if there was a spectrum, I am kind of in the middle. I think looking at it in terms of spectrum where you can be more towards a computational person rather than just being specifically computational is a beneficial way of thinking about the question. Because if you sit down and all you do is you look at numbers, you do not necessarily think it through, you are instead relying on the code. But what if the numbers you are receiving don't make any sense. Now you have to think outside of the box, and you can no longer rely on these computational models that I have been working on. (Peter)

He responded positively to how he thinking his computational identity is in the making and he is working towards improving it to each the higher end of the computational identity spectrum he mentioned.

Women's self-perception of computational identity

Recent research (Garcia et. al, 2018) shows that female participants have a lower sense of computing identity than male students, specifically concerning computing recognition and overall computing identity. For example, in computer fields, Women, Black, Indigenous, and other People of Color have all been shown to be disadvantaged in areas such as training for mathematics, access to technology, role models, and attitudes/stereotypes (Cheryan et al., 2016). Similar to the research from Garcia and colleagues, women participants in this study reported experiences and instances about self-perceptions of their computational identity. None of the men (as reported in table 6) responded that they do not see themselves as computational person, only one woman expressed that she does not associate with being a computational person. Prior research reports that when a woman student enters the university without prior programming experiences, she can feel less skilled than her peers who had an early exposure (Wilcox, 2018).She does not see herself as a computational woman. One interesting thing that came up was the participants' prior computer programming experience. Of the 17 women participants interviewed, 12 were only introduced to programming during the First-Year Engineering program at the Purdue University. The other five women were introduced to programming at the high school level.

Amalia (BME) was underconfident about her programming abilities and says she is not certain if she is a computational person or not. She was undecided because of some negative academic experiences with the instructors and male peers

> I was the only female on my table, and I felt very out of my comfort because all were male, and the majority had computer science experience. The great majority. I had absolutely zero and I had no clue what we were doing. I felt the professor did not facilitate for people who had never even touched any computer language. I hadn't even written a program like print hello. You know? that was kind of a bad experience for me. And at that point I was like, Oh, I am not going to be a good computer person. I am not good to go as a good programming person and this is not my thing. I am very hardworking and very open minded. So, I was like, you know, I am making my thing. I would just learn. About being a computational person, I don't know. I think I have some valuable, computer science skills that I don't think I am the best nor the one worst. (Amalia)

Amalia's negative experiences with instructors, peers, and not being able to be introduced to computational resources early in life lowered her programming self-efficacy and make her feel like she does not belong (Spieler, 2020; McGurren, 2014) however she had a positive attitude toward working persistently to become proficient at computational skills.

When comparing female and male students based on interviews and surveys, female students were significantly lower in their reported computational self-efficacy because of lack of experience; however, they were also more determined to work on building a computational identity. Sarah (BME) talked on similar notes about not being introduced to programming earlier in life as "I think it just depends on like how much technology people are exposed to previously in life. Like I had no experience, I feel like if I was used to it, I would be interested in it faster genuinely". Sarah connected high interest in computational activities with having early access to computational resources. Similar to Sarah's reasons, Goode, Estrella, Margolis (2006) described that fewer learning opportunities at the high school level, as well as pre-set definitions of interest, play a key role in shaping choice. The resulting outcomes were that the field of computer science and what computer scientists do is a small and narrow presentation that limits how women may see themselves in these roles.

4.1.3 I have/don’t have a computational identity

Jessica (ABE) had high computational self-efficacy and when I asked her about her computational identity, she told me,

> at the beginning of college, I would have said no. But after going through a year and a half of engineering, I would say I am just because I define computational person someone who can problem solve because I can figure out how I was going to go through the problems and do it all and it ends up being okay. So, I feel like that kind of justifies me being able to problem solve so I feel yes, I am a computational person. (Jessica)

Going further she told me of her freshmen year experience of working with a mixed gender group that she was perceived as someone who does not knows how to do computational things,

> I never really believed that there was going to be any bias towards women, even though I grew up hearing like, Oh, women get paid less than men in these (computational) things. And I was like, okay, that fact that that's obviously a fact. But overall the attitude there can't be that big of a thing. Then actually, one of the guys in my group during our first project when we were sitting in a group together goes, no, I'm going to do this. Like you're a woman, you, you just can't do it. Like you don't know what's going on. I know what's going on. Just sit back and I'll do this. So that was definitely my first like eye opener experience and I have almost felt that to be true, I guess throughout the whole thing. Not necessarily to that extent, but I felt that there's definitely an engineering man stereotype here where they just think they're better than someone else or they tried to mansplain everything, I guess you could say. (Jessica)

Although Jessica (ABE) explained that she feels she is a computational person she only based the definition of the skills a computational person possesses on problem solving. For her, problem solving meant figuring out how she was going to go through the problems and then getting to the right solution. She talked about problem solving broadly did not talk about exploring multiple solutions. She also talked about the presence of gender stereotyping when it comes to computational tasks.

Meghna (ABE) worked in a male majority project group as a technical leader of the team. She depicted a strong sense of computational affiliation with computational activities she said

> I identify as a computational person. I always have that starting trouble because when you haven't touched a language in a while, it's just you have to remember all the syntax, you remember and once you get it down then things just start flowing in and you are starting to build and build your phone. So, I now enjoy it more than I did when I was younger.”

When asked about her ability to do computational problem solving, she went further saying,

> “I definitely feel like can do well. There's a lot of resources out there. if you don't understand something do, you can always look online. You can figure out how this works. There's a lot of information surrounding it. I definitely do not see it, why I would not be able to do well in it. (Meghna)

Meghna had a positive outlook towards her abilities to perform well on computational activities to develop a computational identity.

While Meghna was working on developing her computational skills, Bryn (BME) was very clear on why she does not view herself as a computational person. The reason she gave for not feeling like a computational person was her comparison of herself to others based on prior programming exposure.

> I do not really see myself as a computational person. Last time in the project I did do like a good portion of the coding. I feel like coming to college has definitely increase my coding skills. I came in with no coding classes, no coding experience because my high school did not offer anything like that. So, even though I've definitely gotten a lot better and I have definitely got better at solving computational problems, I don't really see myself as that person just because I think there are so many people who have more experience or have more confidence or more stabilities in general. So, I guess from comparing myself to other people, I don't really see myself as that computational person. (Bryn)

Despite improving her computational abilities when she compared herself with other peers who were more proficient at programming, she could not see herself as becoming a computational person. Bryn attributed her struggle to internal reasons where she felt that she was not at even playing field as compared to her peers this finding is consistent with (LaCosse, Sekaquaptewa, and Bennett, 2016) where they report that the attribution of failures for women in STEM is associated capabilities rather than external factors and the worst part is that women themselves believe in attributing their failures or struggles with capabilities rather than external factors which can create a disassociation in computational identity.

The students defined a computational person through skills, abilities, and ways of thinking. Based on the emergent themes found from interviews corresponding to the definition of a computational person, a computational person is perceived to possess many abilities above and beyond, only the technical knowledge of computation. The participants described the computational person in close proximity to nerd-genius based on the skills and abilities, however, none of the students expressed the computational person to be socially awkward. Most of the participants either male or female described that their computational identity was in the making.

4.2 Congruence between computational identity and other identities

During the analysis of interview transcripts for answering the second research question, the various identities described by students were coded and then the relation of congruence or incongruence between these identities and computational identity. The findings emphasized which other identities (e.g. gender, engineering.) the participants perceived as compatible or incompatible with the computational identity and why. The focus of the analysis was looking at the balance between these identities rather than the switch between roles. The three major identities the participants linked to computational identity were gender, engineering, and artistic or creative identity. The findings from interview data are complemented with classroom observations and survey data. The findings pertaining to the second research question are divided into the following three sections associated with gender, engineering, and artistic identities.

4.2.1 Gender Identity and Computational identity

"Gender identity" has a strong presence in our lives because, generally, it is biologically and socially imposed (Morrow, 2006). Stereotypes and dominant images of gender and the tasks associated with gender surround us all the time in all societies and cultures because it is typically a social construction (Silva & Alves, 2020). This section provides an understanding of how students describe the relationship between students' self-identified gender identity and computational identity to understand the congruence between these identities and how they perceive their peers and their own abilities to adopt these identities. I did not ask participants a direct question about their gender identity in relation to computational activities or a sense of belonging. Participants were asked an open-ended question, "Would you like to add something on being a (gender of participant) in biomedical or biological engineering, which is becoming more computational day by day?" at the closing of the interview.

Gender stereotypes and experiences of uneven division of computational tasks

Most of the women participants talked about their experiences of gender stereotyping where they felt less valued than men at performing computational tasks. This strong feeling that their contributions were not appreciated made them feel like they were on an uneven playing field when it comes to computation and developing a computational identity. Amelia expressed how she felt that her feminine practices come in conflict with being perceived as a computationally proficient woman and expressed the computational women stereotype around her. Anna conveyed how women are less confident about their computational abilities, and Sarah shared how women take up more of the non-technical work in the classroom on computational projects.

Amelia (ABE) explained that if she was too overtly feminine, she would not be recognized as a computational person. She explained that if she conformed to more masculine norms she might be recognized as a computation person.

> I used to think if women looked [like] women, they do not have time to do anything else. They do not know how to code [because they spend time to took feminine]. Like people are very split. When they look, if they look at a girl who have a tee shirt with an anime character and like and a NASA key chain, they would probably think she can code. Whereas when they look at a woman who wear heels, her purse and makeup on. They think she can't code. I don't know why, but it happens. (Amelia)

For Amelia, appearing to be more tech savvy (e.g., wearing a hoodie, having a NASA keychain) was more aligned with the socially recognized image of a computationally proficient person. Similar to Amelia's explanation, (Berg, Sharpe, & Aitkin, 2018) reported that the stereotypical image of the computer scientist children had was incompatible with that of their stereotypical image of a female due to gendered view of computing as being a male discipline and lack of female role models. These findings are also complementary to (Rudman, Buettner, & McLean, 2013) research on masculine nature nerd-genius stereotypes, which affects women's motivation and STEM identity.

Some of the participants like Anna (ABE) brought up gender stereotypes without a prompt. Anna (ABE) not only talked about herself but spoke up about how women are not appreciated and demeaned and instead of standing against stereotypes women start believing that they cannot do something while answering me her frustration came out,

> I do not understand when someone tells women they can't do something, they act like, "okay, sorry, sorry I ever said that. Or like, yeah, you're right, I can't do it. I don't know why I thought I could." The women are just so timid. And I think that's why in the long run they drop because over the years you just become maybe. I have not done any gender equality analysis, or I haven't read any studies of that. I have no idea but like it in my opinion as a woman you just become used to hearing remarks like you are stupid, you are not good enough, or things just like you are pretty enough that you will be successful no matter what you do. Just like stupid stuff like that as soon as the going gets tough, women just cannot keep going. Not because they do not have the willpower or the intelligence inside of them, but because they are so used to people telling them they do not. Instead of just being like, just letting it all go and saying, I really want to be, I really want to get this degree. I really want to solve this problem. I really want to ACE this class and just like letting it all go and just focusing and studying and just not giving a crap about anyone else thinks. (Anna)

Anna recognized the subtle ways in which gender stereotypes play out and affect women's self-efficacy and confidence. Based on previous research it is reported that women have low confidence and fear of failure in STEM subjects (Stoilescu & Egodawatte, 2010; Vekiri, 2013). These findings are consistent with prior findings that the expectations of women's fit in a field come from inside women themselves, reflecting a bias in attributions of their own skills. (Sekaquaptewa, 2011). Anna's response is depicting low self-confidence in women not only towards programming but other academic aspects as well.

Some women participants also talked about experiences of uneven gendered computational task sorting in the engineering classrooms. Sarah (ABE) mentioned instances where she felt like women engage in particular tasks like report writing which is not as computationally intensive as programming.

> I remember making this note to my engineering team in second semester. I said "do you notice that all of the people that are doing most of the coding are the guys in the group and then all of the people that are mostly writing the reports are the girls. I just want to know why this happens?" she took a pause and looked down and after a heavy breath she said "I really do not understand because we all here want the same thing. But that's just one like it falls back to, and it was so crazy for me to look around the room and I am seeing this myself and even myself, I was falling into that role. I was writing the reports and I think it is kind of just being an engineering, you (women) are already kind of like breaking a standard that's set. (Sarah)

Sarah may have been referring to that being in engineering is already like breaking a standard, working on technical tasks like programming will be an additional standard to break. She went on to say,

> I do tend to be a person where I am like, if they (men) want to code and they (men) are good at it, how could I deny them to do that? And then, you know, I am more complacent when I can tell they (men) do not want to explain it to me, to that I'll just be like, okay. (Sarah)

Goode et al. (2006) indicated that in computer science classroom environments, female students often have adverse experiences, where greater male technology experience and female alienation are part of the cultural environment. My findings were consistent with Meadows et al. (2013) that not only do women typically take the least technical roles, they are also less likely to acknowledge this gender bias. As unimportant or supporting roles are assigned to reflect the social stereotype of men in engineering as experts and women as supporting roles, women like Sarah may feel unvalued by the majority (Meadows et al, 2013).

Uma (BME) told me about a classroom experience where she felt unheard because of being a woman. She told me "I remember an incidence of being looked down on based on my gender in one of the labs" she was working on a programming-based problem with her group, she explained,

> I was put with a girl and then this guy. And he was trying to take over and do all the code and he was not letting us [women] do anything, right? One time, like I was saying like, Oh, you should do this and this. And I gave him a suggestion. He was like, no, no, no, no, no, no, that is not going to work. And then five minutes later he said, Oh, I should have done it, dah, dah, dah. And it was the exact thing that I had told him, so I said that's what I told you. And he was like, well, whatever. And he did this so many times…… I mean we got good grades, but did it make me feel better? Did it make me feel good? No. Not because he wasn't listening to like what I was saying? And the worst part is like he wouldn't even say, Oh, you were right. I should have done this. He would say, Oh, I can't believe, I didn't think of this. (Uma)

Uma wanted to feel heard and acknowledged for her suggestion to amend the computer program.

Anne (ABE) mentioned that she never felt that engineering was masculine because of how she was brought up and her early introduction to computational experiences; however, she acknowledged that experiences of gender stereotyping do occur in engineering,

> My grandpa, my dad, my uncle are all engineers from on my dad's side. And then my mom's side is very technical as well. I guess just being raised around my grandpa a lot, he really pushed me that just because I am a girl does not hold me back or anything, I can do everything that my brothers can do. I know that I can do

> anything. Especially with having so many engineers in my family or really like pushing me for engineering and like help me do my best. I think me personally, I have been really lucky to not feel discriminated against in engineering, just being a woman. But I know that unfortunately, that experience differs for a lot of different people. (Anne)

While Anne expressed that she did not experience gender discrimination, she suggested that this is something other women and other female students do encounter. It is reported in research (Powell, Bagilhole, & Dainty, 2009) that in order to gain male acceptance in engineering classrooms women students perform their gender in a particular way by utilizing certain coping strategies: acting like one of the boys, accepting gender discrimination, achieving a reputation, seeing the advantages over the disadvantages and adopting an “anti-woman” approach. Anne may not perceive that she experiences gender bias because she has figured out ways of feeling like she belongs in engineering. This reauthoring of what it means to be a woman, engineer, and computational person indicates the ways in which experience varies.

When Lisa was asked about any good or bad experience she had in engineering, she reported that she did not face any gender discrimination herself. However, she witnessed incidents of gender discrimination in the engineering settings around her.

> “I guess a bad experience that I have had. I guess in some classes hardly ever really, I have felt like there has been an issue between being a female or male, but I have seen it before. Not as a student, myself as a teaching assistant in engineering classes where women feels like either feel inferior or treated inferiorly to men. (Lisa)

She mentioned instances of gender discrimination she has observed in engineering classes without being prompted to talk on gender. These findings are consistent with prior findings where women feel unwelcome or excluded in STEM spaces (Sekaquaptewa, 2019).

Interests, capabilities, and gender

Interests and capabilities are independent of gender; however, interests and capabilities are often associated with gender in male-dominated environments like engineering. In our conversation about interest and proficiency, Meghna (ABE) described how she found struggled to make meaningful connections with other women who might have similar interests. Her experiences were that her interests were not well aligned with what most women found interesting.

> I noticed very often that the skills I like, they do not help me fit in with other people in my gender. I picked things like learning video games by just hanging out with

> my guy friends. It's just I wish I had met more like-minded females at a young age. I wish I did not want girlfriends as again I wanted in childhood, because as a kid, if you want friends. I am a girl. So, my friends should be girl. Right? So, it is just that if I had thought I am a person, I like these things. I want friends who like these things. Game changer! I would not have cared as much that I did not have a single girlfriend. At least I had people who like similar things and interests. (Meghna)

She described how she had interests that align with the interests of a computational person, but when she was younger did not find other girls or women that shared these interests. To develop meaningful female relationships, Meghna felt that she would have to minimize her interest in chess or programming. Her quote indicates that to fit the larger feminine social norms, she described a need to let go of her computational interests, which depicts an incongruence between feminine and computational identity.

Mary (ABE) expressed during a follow up response to a prompt question that people tell girls to pursue coding when people think the girls will need the skills, but not because they think girls would be interested in it.

> I don't know if it's necessarily that I am a woman, but I feel we don't do a lot of computation just by nature. I have all my friends who are really into coding outside of class all happened to be guys. And I don't know if that's a coincidence or not it could be, I don't know. it is hard because sometimes it feels like there are not opportunities, but like girls aren't really like encouraged to take on these extra like challenges for coding until you decide that it's a part of what you want to do. Like for example, in high school, I never really felt like anyone encouraged me to look seriously more seriously into coding until I told people I was going into engineering That's when they started recommending coding related stuff to me. I don't know it's not that there are no opportunities, but it feels like girls are not pushed to like to pursue them until it becomes relevant to them. Like no one tells a girl to go, oh you should look into coding. Because I think you would actually enjoy it, but you should look into coding because you're going to need it later. (Mary)

Based on what Mary reported, when the instructors recommended that she learn programming because she was going into engineering, she felt that programming was introduced as a skill or tool rather than as something that would be of interest to women. Interest is a subcomponent of computational identity based on the computing identity framework and if women engage in thinking that programming is a skill rather than interest, they might not be able to grow interest in computational activities.

When doing classroom observations, I observed that Kate (ABE) was taking on a lead role concerning computer programming and students around her irrespective of gender were asking her for help on computational tasks given in classroom. She was doing computer programming on her laptop during most of the class sessions. When I asked her about her deep interest in computation she replied with excitement,

> I have always been more interested in like how things work or how computers work, and I have been always more like tech savvy or techie. It's just in my nature. I honestly couldn't tell you why because I think it's also might be that my parents are not that experienced with computers. So, I have had to do a lot of like tech things for them and a lot of that bridging of the tech things from their generation to mine. So that may also be a contributing factor. It's just also the fact, I am not afraid of a challenge. I do prefer coding a lot for that. (Kate)

Only nine women out of forty-six were assigned or preferred to be in either of the two technical roles (technical lead, and strategy analyst) in comparison to eighteen men out of thirty-six, which depicts the unequal task sorting among student gender.

Gender Comparison Based on Trends of Computational Self Efficacy

In addition to interviews, participants were asked to complete post-project surveys, to understand the trend between women and men's computational modeling self-efficacy in the course. Where they were asked to respond to the Likert scale item: "how comfortable are you with your ability to perform computational modeling?" the students could choose a response between 1) Extremely comfortable, 2) Somewhat comfortable, 3) Neither comfortable nor uncomfortable, 4) Somewhat uncomfortable, 5) Extremely uncomfortable.

In Figure 6, I compare the trend between overall women and men participants' computational modeling self-efficacy from the thermodynamics course side by side using Sankey diagrams. Based on the students' reported computational modeling self-efficacy during each project, Sankey diagrams were created for the total class as well as for the interview participants to understand how computational self-efficacy changed for women and men during the course. A Sankey diagram was specifically made for interview participants to understand if the trend of computational self-efficacy was similar to the rest of the participants and also to see the individual change in self efficacy for each interview participant. The height of each panel or node depicts the number of students in each comfort category. The "Comfortable" node includes responses of extremely comfortable and somewhat comfortable whereas the "Neutral or Uncomfortable" node includes responses of neither comfortable nor uncomfortable, extremely uncomfortable and somewhat uncomfortable. Responses are combined to understand the contrast between students who had an increase in confidence vs no increase. The story that emerges visually is told by the difference in height of comfortable nodes between the women and men group. More women who had a low computational modelling self-efficacy became comfortable by the end of the final project in the course.

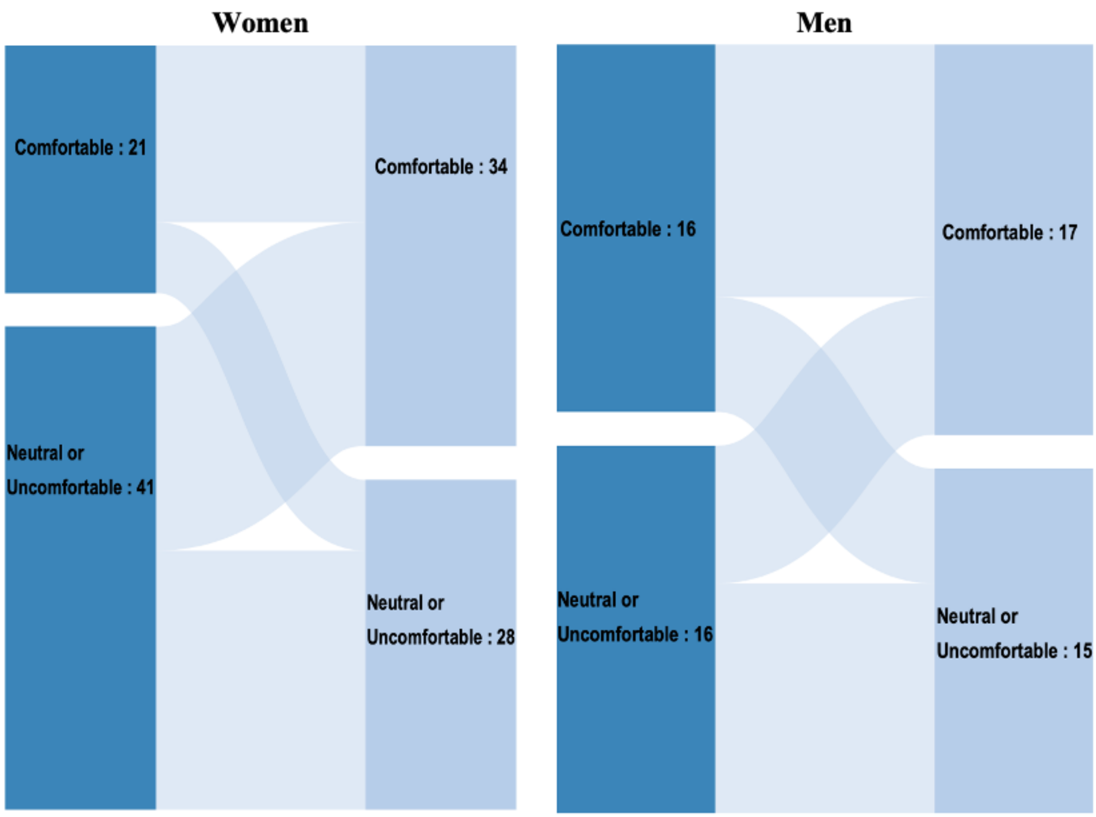


Figure 4. Trend of total participants between 1st and 3rd project.

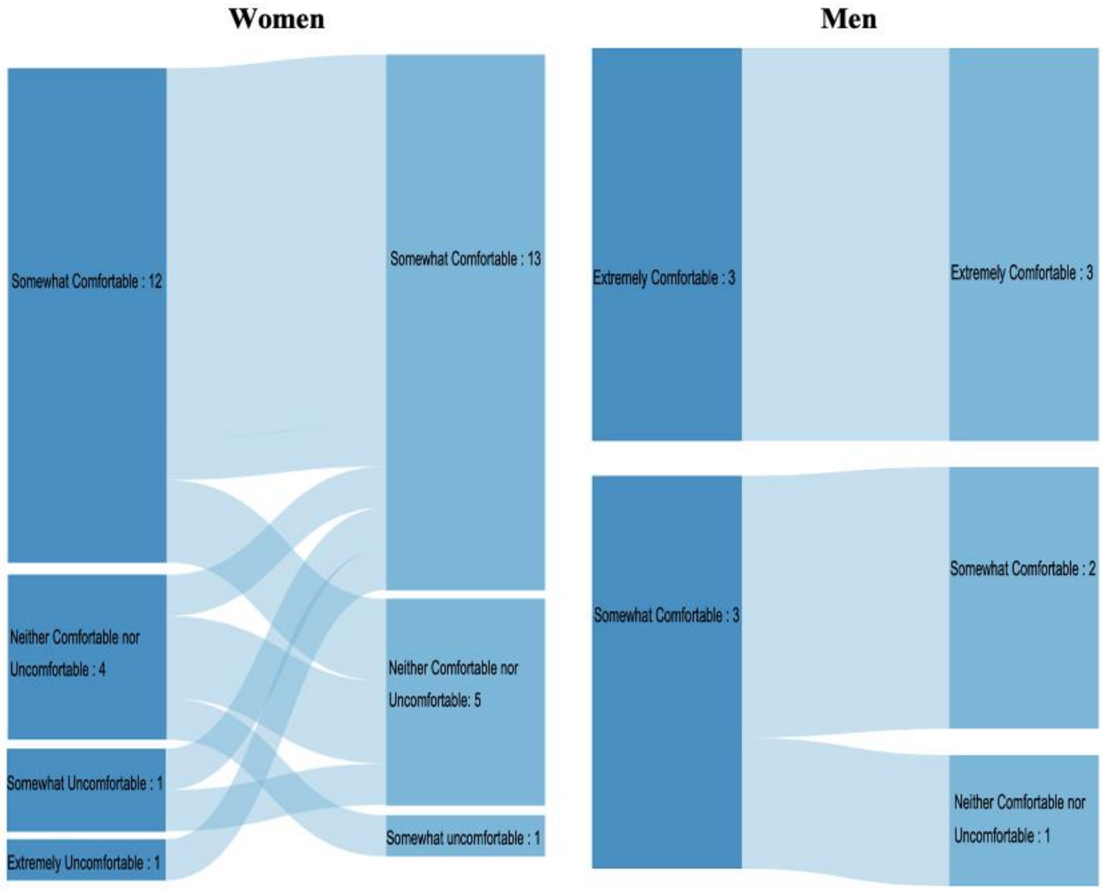


Figure 5. Trend of interview participants between 1st and 3rd project.

Based on the visual analysis of Sankey plots, the overall women participants had more change in the self-reported computational competence as compared to the men participants. There is a considerable increase in the computational modeling self-efficacy for women in the overall class. In the interview participants, there was more change in the women participants' computational modeling self-efficacy as compared to men. The interview participants computational self-efficacy trend was more or less the same as the whole class. This means that the course design and instructional changes were effective in promoting computational self-efficacy in women students.

4.2.2 Engineering identity and computational identity

Some participants discussed engineering identity and their computational identity in follow up questions. When Emma (ABE) was asked a follow up question on why she thinks an engineer and a computational person are different, she explained at length,

> Being an engineer is about what I was saying earlier its like applying your knowledge to make something new or make something better. But, being a computational person, I would say it is applying like more of mathematical knowledge. Make something better. I guess I see engineer as designing what needs to be done and then a computational person is like implementing that plan. An engineer's going to say, okay, we need to figure out a way to make this run this much faster. And computational person will say, okay, these are all my variables and I need to manipulate them all so that I get the right output. (Emma)

For her an engineer is the visionary and the computational person is the practitioner, they work with each other in order to be successful which brings out the congruence.

Similarly, Maggie (ABE) expressed how engineering and computation are intertwined, and to be a successful engineer one has to be proficient in computation. In a follow up question when I inquired of her, do you think being an engineering person and a computational person is similar or different? She replied, “I am having a hard time differentiating the two because I feel like you need to be a computational person to be a successful engineering person.” For her and Emma being computational was inherent to be a successful engineer.

4.2.3 Artistic identity and computational identity

An identity that came up when students were explained about their computational identity was the mention of artistic or creative identity. Fazal (BME) expressed how he saw himself as more than a computational person because he had an artistic side,

> I see myself as more than just a computational person and maybe a lot of people think a computational person only kind of has like their head in the books or it's just like looking at the computer and does not have a lot of other skills, but I have more skills beyond just that. To a substantial part, I am a computational person, but not entirely. If the only things I did were like code or like math or computing things, really anything that requires only technical skill then okay. Like if I did nothing like artistic. I believe I have an artistic side too, which makes me more than a computational person. (Fazal)

Fazal separated artistic and computational identity in his explanation. Fazal had the nerd stereotype about a computational person and by complementing it with artistic identity he enhanced himself from the stereotypical nerd identity (Kendall, 2011; Wong, 2017). Although John (BME) did not mention anything about artistic or creative identity he did mentioned how the nerd stereotype keeps people back from computational activities "I think a lot of people who don't like it [being recognized as computational] because maybe like there's like a stereotype that like nerds do it, that might turn them away." John and Fazal did not wanted to adhere completely with computational identity because of the nerd stereotype.

Another student Sarah (BME) spoke up about her artistic/creative identity being in conflict with computational identity and gave a different reason for this conflict as compared to Fazal. She felt she could not relate to computational identity because, "I feel like the creative people who are more artsy would not like something as structured as coding and all these loops and iterations and things like that." For Sarah, having a structure while working on something was against her creativity.

4.3 Pedagogical support for computational identity development in the thermodynamics II course.

The findings from this question provide insights into the interaction of the course design with the student's development of a computational identity. As per the theoretical framework, interest in computational activities, being recognized as a computational person, and competence in computational activities are combined constructs of computational identity development. To understand which aspects of the course supported computational identity development, data sources were analyzed qualitatively through the analysis technique of thematic analysis except for the survey responses. The inclusion of Juypter notebooks improved student interest and competence. Group and individual computational projects increased computational competence and recognition. Discipline-focused programming activities increased participants' interest in computational activities.

Table 7. Pedagogical aspects that supported computational identity development

Identity Development Constructs	Aspects of the course which supported computational identity development
Competence	• Participating in collaborative learning projects. • Team Project based learning where each project was developed through computational modelling followed by individual computational modelling-based project.
Interest	• Switch to technical roles in team-based projects. • Course content-based programming opportunities.
Recognition	• Participating in team based computational modelling project gave participants opportunity to help team members on technical aspects of the problem being solved. This activity generated self and social recognition as a computational person. • Individual computational modelling-based project.

Theme One: Inclusion of Juypter notebooks improved student interest and competence

In comparison to the traditional design of thermodynamics II, the course offered in spring 2020 used Jupyter Notebooks. A Jupyter notebook is a web-based, interactive programming environment with open source licensing. In each lecture, students got a link to an online worksheet that had the lecture notes contained as well as the computing exercises for that class period.

The students were encouraged to bring a laptop or tablet to the class. All computing exercises were in Python. All the computing exercises were related to the provided discipline-based examples. During the early classes, students were requested to modify an example script to change the inputs or to add new variables to a system of equations. For each computational modeling-based project students were provided with a Jupyter notebook link with had some related code snippets included to start with.

Maggie (ABE) explained the nature of class as highly computational when asked about what makes this course different for her, she expressed,

> The course definitely has computational aspects, especially in the projects. And then thermodynamics is very computational, and it is very math heavy I have found.

> I would definitely say that it's more of a computational class rather than one of the more like conceptual classes. (Maggie)

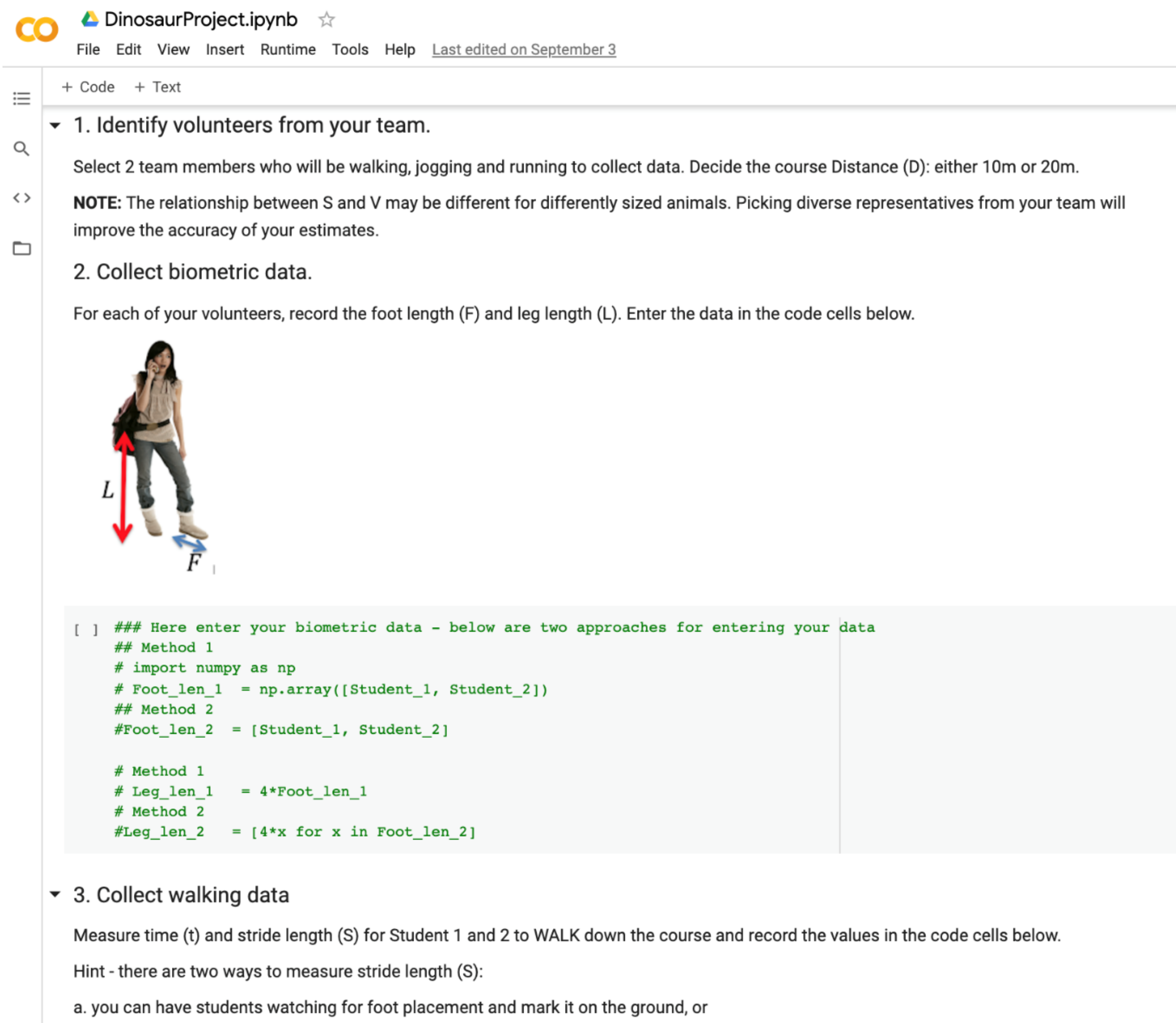
Maggie recognized that the pedagogical approach, as well as the content of the class, were both computational which helped her practice and improve her computational skills.

When asked about the role of this course towards Meghna's interest in computational modeling, she described,

> I really do like how this class is structured to be more computational. I think there's more benefit in it because when we do things by hand it's nice, but the reality is in the real world you're not taking a paper pencil, you're not drawing out every system and you're not hand calculating it. You're using computing methods to do it I think it's far more practical than doing everything by hand and learning like the rudimentary ways to do. (Meghna)

For Meghna, the pedagogical approach of using computer programming was more practical and helped her practice program solving through computer programming.

Through analysis, it was observed that the remodeled design of course based on Jupyter notebooks had an influence on the constructs like Interest and Competence in computational identity development. During each class session, the students were given a lecture on the concept being covered in the session, followed by an active learning-based team activity during which they had to discuss the solutions and programming them in the guided learning Jupyter notebook. The Jupyter notebooks were written as linear narrative documents which provided students guidance in proceeding through the computational tasks step by step. The notebook offered support by providing guidance in sub-tasks and simultaneously giving students the possibility of inserting and running code snippets using the Python programming language. In Figure 8, the code snippet from Jypyter notebook of first project is show in green colored font.



DinosaurProject.ipynb

File Edit View Insert Runtime Tools Help Last edited on September 3

+ Code + Text

1. Identify volunteers from your team.

Select 2 team members who will be walking, jogging and running to collect data. Decide the course Distance (D): either 10m or 20m.

NOTE: The relationship between S and V may be different for differently sized animals. Picking diverse representatives from your team will improve the accuracy of your estimates.

2. Collect biometric data.

For each of your volunteers, record the foot length (F) and leg length (L). Enter the data in the code cells below.

L

F

```
### Here enter your biometric data - below are two approaches for entering your data
## Method 1
# import numpy as np
# Foot_len_1  = np.array([Student_1, Student_2])
## Method 2
#Foot_len_2  = [Student_1, Student_2]

# Method 1
# Leg_len_1   = 4*Foot_len_1
# Method 2
#Leg_len_2   = [4*x for x in Foot_len_2]
```

3. Collect walking data

Measure time (t) and stride length (S) for Student 1 and 2 to WALK down the course and record the values in the code cells below.

Hint - there are two ways to measure stride length (S):

a. you can have students watching for foot placement and mark it on the ground, or

Figure 6. A Screenshot of Jupyter Notebook Activity from Thermodynamics II

Based on Victoria's (ABE) responses to the pre and post course survey as well as her responses on the post course surveys, she had an observable increase in her computational modeling self-efficacy. When asked what helped her gain the confidence in attempting more computational tasks she replied,

> I think in this course we have most of the code already given so I think it would be hard to do the code on my own because I always have the beginning problem with writing the code so I think that helped and also the fact that the code given was more applicable to my discipline. (Victoria)

At the conclusion of interview, she added, "In the beginning of the course I felt kind of uncomfortable with like even just the structure given, but now I definitely feel like totally fine with being given the structure, but I think I could start to transition to not having the structure now." For Victoria, starting to program with a narrative and a part of code written to start with helped her with getting through the starting trouble of writing a code.

Maggie (ABE) also described how having a structure to start with not only saved her time but also made her understand that there are different ways of structuring the programs; it helped her to understand another person's way of structuring code.

> Having the structure of the code given definitely saved time. It helped with like the pure programming aspect. In that regard it was helpful. It was tough kind of figuring out how they made the structure for some of the problems, like it's tough to say but I feel like you can code things multiple ways. trying to figure out what their train of thought was a little hard, but I think overall it definitely helped. (Maggie)

She had the opportunity to understand a different perspective on structuring the code which improved her competence. She also explained that it was *difficult to understand how the instructors made the structure for some of the problems and figuring that out was tough for her.*

Theme Two: **Group and individual computational projects increased competence and recognition**

The projects and classroom assessment activities were designed based on computational thinking components in the Jupyter notebooks. The course had three major projects. Each project has problem solving as well as programming-based components. Two pre midterm projects were group projects where each group had five participants whereas the post midterm project was an individual project. In the group projects, participants had the choice to select a project role provided in Appendix H.

When I asked John (BME) if he had a preference for individual or group projects, he replied with the pros and cons of both types of projects.

> I would probably prefer a little bit of both. Group work's fun but it gets old after a while. I like it with people I know, it's much easier, but I kind of do enjoy individual stuff because I do not have to depend on somebody else, especially when you are graded. But I like about group work that you can do like bigger, more cooler things. But I know I would get stressed. I want a group because you have to rely on the results of other people. But genuinely if I know the people that works well, you could trust them. (John)

John talked more about the benefits and drawbacks of a group project and individual projects

Annalise (ABE) mentioned that working in the group was useful because of having multiple perspectives for solving the problem. She also saw a benefit in being able to ask the group even when she faced a barrier when programming individually, which improved her programming confidence. She elaborated,

> In [a 200 level BME course] when we did have time in class to work, we were all kind of contributing to the code, trying to understand like different ways that we could try it and how we could even start sometimes. But then I think a lot of times, like if it didn't get finished, which it never would get finished in class, one person would go take the code home in particular and finish the code by themselves. And then we all kind of had our area that we were working on of the project, but when we were all together, we helped each other. And then in [another 200 level course which had a computational final project], I felt like I was doing most of the coding by myself, but whenever I had a question, I could ask my group members. There was always a lot of different kind of viewpoints and that helped develop the code in that class." She further expressed about working individually "doing the individual project helped me get a lot more understanding of the coding process and how I can apply it. (Annalise)

Victoria (BME) expressed that she is comfortable with attempting to write a computer program on her own after the exposure to programming in the course. She expressed "I am fairly comfortable with computational activities now. I don't think I could write like an incredibly complex program, but now I could probably write approach writing a program on my own, depending on the problem for this course". The course provided Victoria the opportunity to practice through computational projects.

Designing the course to include a variety of assessments (projects and classroom activities) gave students the chance to practice computer programming in multiple course problems and projects. Some participants responded that the design of the course that included both group and individual projects was beneficial for gaining computational competence.

Engaging in computational activities provided the participants with an opportunity to be recognized as computationally proficient during group interactions. Jessica (ABE) explains that when there was computational problem solving being done in a group,

> When I worked in groups, I feel like it's was probably a good thing because it helped me think in a different way than I have ever thought before. So I feel like in general, I like the idea that it's going more computational, and then hopefully men as I go on through, all of this will become more accepted or I'll become more accepted to

> guys and they will just be like, okay, yeah, like it's totally fine. We are all equal. (Jessica)

For Jessica, when it came to computational problem solving engaging in mix gendered groups helped her think in new ways. She also expressed that these opportunities will serve as experiences where men will come to realize that women are equally competent when it comes to computational tasks.

Kate (ABE) also spoke about being recognized through the eyes of her peers. She explained that she recognized herself as computationally proficient because in this class her peers asked her for help with computer programming or problem-solving related activities.

> I think my peers come to me for, whatever they are feeling down and also just for the whole like coding aspect, I do have like, I guess I like a vaster knowledge of programing because I do know Python, Ruby, R and all of these like HTML, kind of programming languages. My peers or group always come to me for like help with that or if they need help with like a different assignment. (Kate)

For Kate, being asked for help in computational tasks made her feel recognized as a computationally proficient person.

Students were asked to assume a different role for the second project as compared to the role they had in the first project. Victoria (BME) took a non-technical role during the first project but switched to a technical role for the second project. She explained about taking the technical group role as a valuable experience towards her computational confidence and having self-recognition and competence.

> I was the strategy analysist in the second project. I guess in the initial group formation nobody really had a preference about roles. And then, I asked Who is feel comfortable with coding? everybody in the group was like not me. I kind of like was assuming, I guess, kind of this leadership role. So, I was like, you know what, like, I feel like I can take this technical role if anybody else has literally no idea because I felt more comfortable like asking TAs or asking other friends for help, I guess, with that role. Because I went to [a] more technical role, my confidence increased between the projects. (Victoria)

Participants reported instances of social interactions during the course as moments when they felt recognized as computationally proficient. These instances served as ways in which the participants developed self-awareness as well as ways, they received social recognition. The various ways we recognize self and others play an important role in shaping our identity and sense of belonging.

Providing students with social interactions in the context of a computationally intensive environment gave opportunities to become or be recognized as computationally proficient.

Theme Three: **Discipline focused programming activities increased participants' interest**

The projects and computational activities given in the Thermodynamics II classroom were discipline focused. The programming was embedded in the narrative of the concept each lecture was conveying. John (BME) mentioned about the computationally intensive design of the course that

> it's made me appreciate the application of programming a little better because it's more like direct, it's more like you are focusing on a product that is like a supplement. because the problems are more discipline based now. I kind of liked that part. Because I feel when you do just the coding stuff like coding, you know that itself is really boring. I like it more when coding is discipline based because I can focus on like that topic and like if that's just a tool, I don't mind doing it. Like I wouldn't like to choose to do it, but I don't mind it as long as like I kind of enjoy having the more like discipline integrated stuff. (John)

For John, having to work on programming problems and projects which were relevant to his discipline increased his interest in computer programming. Earlier in the interview, John mentioned that he transitioned from computer science because he did not like programming however, in this course he said that he does not mind doing programming because he is using programming as a tool to solve the discipline-based problems which he likes.

Similar to John, Jessica (ABE) also found the discipline-based programming problems helpful. She explained that she got more interested in the computational activities because the programming problems were more specific to her discipline,

> the problems in this course are much more oriented with our major. When the programming problems are not catered towards my major it makes programming pretty uninteresting for me. But now that I am in this course where it's easy to see how it can be applied to my field and like you definitely can see yourself using these techniques later in your career. It's just a lot like there's so much more motivation to get the problem done and it's easier to comprehend as well because it's in the same discipline. (Jessica)

Jessica introduced a few new points that were distinct from John's observations, because of the discipline-based programming she could see the practicality of using programming in her future career. She also admired how learning programming was earlier for her because she could understand the context of the problem.

5. DISCUSSION, CONCLUSION, AND FUTURE RECOMMENDATIONS

5.1 Overview

The previous chapter presented the research findings related to each of the three research questions. This chapter will focus on discussing those findings and linking them back to the literature, starting with the results from each of the research questions. The proceeding section includes suggestions for engineering instructors and students and opportunities for future research in engineering education. The chapter closes with the overall conclusions and contributions of this research.

5.2 Discussion and Synthesis

Research Question #1: How do biomedical engineering and agricultural & biological engineering students describe their computational identity during a computationally intensive course?

At the time that this study was undertaken, I was not able to find any other research related to how students define what it means to be a computational person. However, based on the previous literature used for the theoretical framework of this study, researchers have looked at computing identity by identifying three sub-constructs: interest in computation activities, competence in performing computational activities, perceived recognition as a computing person to perform computing-related activities (Garcia et al., 2019; Mahadeo et al., 2020). The aim was to understand if students describe having computational competence, recognition, and interest as essential to having a computational identity or not in their definitions of a computational person. The following four emergent themes were found from analysis based on student interviews in this study:

1. A computational person is proficient in mathematics, programming, and problem-solving knowledge, skills, abilities, and ways of thinking.
2. Participants shared the belief a computational person possesses the ability to make decisions based on computational work.
3. A computational person can translate between human language and machine understandable code (through pattern recognition and/or decomposition)
4. A computational person can encompass multiple and possibly heterogeneous viewpoints and representations.

The students defined a computational person through skills and abilities which correspond to the competence construct and perceived recognition to perform computational thinking related activities of the theoretical framework. Students described the skills (programming, mathematics, problem solving, etc.) that a computational person would be proficient at, having that proficiency in self improves their competence in computational work while recognizing the same skills in others is associated with perceived recognition of those skills. A computational person is recognizable by not only the skills and abilities to perform computational tasks, but also how they perform computational tasks.

None of the students who were interview for this study described a computational person as having an interest in computational activities in their responses, however the students did express their own interest in skills they associated with a computational person. Based on the emergent themes found from interviews corresponding to the definition of a computational person, a computational person has sophisticated skills and is perceived to possess many abilities above and beyond, only the technical knowledge of computation. The majority of students said their computational identity was “in the making.” When asked what would make them feel like they are a computational person, they responded that a certain skill or ability is missing, or they are working on improving a certain skill or ability. When students have a checklist associated with the definition of a computational person in their minds, it becomes difficult to adhere to it completely, and the students keep on striving to make improvements. The definition is complex just like any other identity because there are no boundaries set to test abilities of programming or problem solving (i.e., how many programming languages will a computational person be proficient at? or how many perspectives or problem solving approves can this person think of? or what is the efficient time in which this person will perform all these calculations). Based on the students’ responses, it would it appear that they have a mental checklist of skills and abilities a computational person should accumulate to be identified as computational. Having a checklist approach towards building this identity limits students’ perspective where they only see a set of skills and abilities to learn thus, there is a risk of details being avoided and of the same or similar skills and abilities, and ways of problem solving satisfying them automatically.

The students who had very high or very low computational identity had a view that computational person has to be proficient at fewer skills (limited set of skills) than other interview students described. The negative perception of a computational person was associated with the nerd stereotype were engaging in excessive computer programming or making decisions just on the basis of statistics and not involving human intuition in the decision-making process, the computational person was also associated with being emotionless were some examples. This finding supports research reporting that undergraduate students associate computationally proficient students with nerds (Kendall, 2011).

Research Question #2: In what ways computational identity is in congruence or in incongruence with other identities students hold?

There were several discoveries worth noting within the findings for the second research question. Previous research reports gender stereotypes in computing disciplines (Mendick & Francis, 2012; Peters & Pears, 2013) as one possible cause of the underrepresentation of women in computing disciplines. Participants were asked an open-ended question of their views on gender and BME/ABE becoming increasingly computational and questions related to group interaction in order to understand the congruence between gender and engineering identities. Women participants reported incidents of gender stereotypes and unequal division of computational tasks.

If someone sees a domain or role as congruent with self, they can more readily develop an identity. When incongruence happens, it causes identity conflict that can lead to coping strategies to minimize one's identity in a particular context to create fit or to leave. Many individuals are likely to be incongruent with the characteristics of the nature of tasks they perform or the people with whom they engage. When students see antisocial personalities as the dominant stereotype to adhere to, they start losing the attraction or feel like they do not belong. Computing being a masculine discipline presents these stereotypical characteristics, and both men and women who want to depict acceptance in this masculine field adapt to these characteristics (Connell et al., 2015; Akpanudo et al., 2017).

A major negative gender problem that affects many women who want to take computing as a discipline is stereotypes. As in many other sectors, technology stereotypes are integrally related to much broader cultural gender stereotypes (Perry & Cannon, 1968). Best et al. (1977) suggested that the stereotypes of men are associated with categories like “rational, independent, egotistical, and unemotional.” A woman is described as being “affectionate, sociable, sensitive” (pp. 4). Parallels can be found when these male stereotypes are compared with the characteristics of scientists. This contrasts with the generic image of women, in which it was found that women tended to be sociable and concerned (Best et al., 1977).

A mix of men and women participants like Fazal, Osama, and Kate defined a computational person as someone who spends excessive time on computer programming, so they do not have time to socialize. They responded that they partially adhered to a computational identity and not fully because they engage in social activities instead of performing computer programming all the time. They had found their ways to be in congruence with the discipline without adhering to antisocial stereotypes. In was observed through classroom observations, to create a fit in the masculine space, they started dressing up in masculine ways like wearing a hoodie and appearing to not care about their dressed-up appearance so they can appear to be fit for the tech savvy environment. On the other hand, they vocalized being involved in social activities instead of working excessively on computer programming. Based on women quotes mentioned in section 4.2, women saw computational identity as consistent with engineering masculine social norms. Some female interview participants reported that their computational identity was in the making or that they had a strong computational identity. These women interpreted that they found ways to maintain both their identity as a woman and their computational identity. Women who reported about their strong computational identity developed the computational identity based on coping and hiding strategies like adapting to tech norms for being recognized as a computationally competent person. Many of the female participants did not note any incongruences, and also the male students did nor did not talk about gender/ gender congruence.

When participants were asked what it meant for them to be an engineer, some of the participants described having proficient skills and recognition in mathematics and engineering in congruence with computational identity. Emma, Amira, and Maggie described that an engineering and computational person had intertwined skills of computation and problem solving. They saw their engineering identity and computational identity as congruent.

An important finding which emerged from participants' responses to the question, "Are you a computational person?" was the mention of a creative or artistic identity. Three participants, Fazal, Jim, and Sarah, mentioned that their artistic identity was incongruent with a computational identity. According to these participants, a computational person is certainly based on numerical calculations; however, an artistic person's creativity comes with uncertainty because not all creative ideas will be successful. These students felt they either partially had a computational identity or had no computational identity because of their creative or artistic identity.

Prior research illustrates that divergent thinking processes are associated with creativity. (Dane, Baer, Pratt, & Oldham, 2011). Based on findings from the first research question, some students described a computational person to possess the ability to think divergently in multifaceted ways. The students who had an incongruence with computational identity had a narrow or stereotypical perception of a computational person as a robotic decision maker instead of a divergent thinker. They indulged in the rationalist decision making ideology and made positive value judgments. They considered this to be essential to “good decision-making” indicating that all of these students had been socialized into computational ways of thinking even if they had differing levels of self-identification as a computational person.

Research Question #3: What aspects of the course impact students' perceived competence to perform computational modeling and programming?

The literature talks about how computational thinking-based instruction combined with collaborative learning is beneficial to improving computational skills and capabilities. Based on the framework adopted for this study, the discipline-based computational identity is evolved through 1) developing interest in computational activities, 2) being recognized or recognizing one’s self as a computational person, and 3) having competence in computational activities. Students reported on different aspects of the pedagogy, which made them more comfortable and confident taking on computational tasks. The participants’ responses were analyzed to understand which pedagogical strategy enhanced each construct of computational identity development.

Pedagogical approaches in computer science education that de-emphasize prior coding skills and used collaborative group learning have shown increased persistence of women in computer science, most prominently at Harvey Mudd College (Dodds et al., 2012). Collaborative learning in this course was incorporated through 1) Turn-to-your partner in-class exercises where students solved computational modeling-based problems in a team of seven people and 2) Computational thinking-based projects in a team of five people. Collaborative learning (CT) was defined as spontaneously helping group members learn CT concepts in the scope of this study. The small groups formed as a whole contributed to each member's learning by providing explanations, sharing diverse problem-solving strategies with one another, or simply struggling together.

Some of the female participants, such as Annalise and Victoria, reported that collaborative learning contributed to an increase in confidence in performing computational activities. When solving complex problems together, they went through a process of collecting information, deciding what to do, and communicating with others about the effectiveness of their proposed solutions. Social influence interacted with their personal experiences, making peer groups, and group interactions important factors in their learning. Based on the self-perception of their performance in individual projects (Zhang, 2014) followed by a collaborative learning experience, they expressed improving their computational modeling self-efficacy to gain self or social recognition. Hence, the inclusion of both collaborative and individual learning experiences in this class made students more aware of their competence and helped students gain recognition in computational activities.

Participants' interest in computational activities was gauged by introducing team roles based on technical and non-technical roles. The participants were given the opportunity to build the team infrastructure based on team role assignments (responsibilities assigned with each role were provided by instructors). The participants were directed by the course instructors to actively switch from technical to non-technical (vice versa) roles during each project. Switching between technical or non- technical roles helped each individual feel responsible for the computational tasks of the project, which in turn improved interest in the computational activities' component.

Previous research has reported that instructors who integrated computer programming into their college courses faced a complex challenge as students often had difficulties learning the fundamental concepts of coding due to a lack of prior knowledge and interest (Robins, 2003; Qin, 2009). Hence, to promote the participants' interest in computational activities and support those students with less prior experience with programming, programming exercises, and activities that were embedded in the course content, were introduced through online Jupyter notebooks.

When students who had minimum prior exposure to computer programming could compile and execute programs in this online learning environment, it gave them the working confidence that can compile and run programs without getting lost in the nits and grits of the programming language. The students were also given the program's skeleton in the notebook for each activity to reduce their sense of discomfort towards writing a computer program from scratch.

5.3 Research Contributions

This research has contributed to the literature on students' definition of a computational person and computational identity by investigating the experiences and perspectives of sophomore students enrolled in a biological engineering thermodynamics course. This contributes to the needed literature on the computational identity of engineering students. Additionally, this study gives insights in to our understanding of the interplay between the computational and gender identity of engineering students. This understanding can help provide a foundation for a future engineering workforce that has appropriate gender equity. The research was conducted with a computing identity (Mahadeo et al., 2020), social identity theory (Stryker & Burke, 2000), and symbolic interactionism (Burke & Stets, 2009) based theoretical framework. This adds to the literature about how to broaden participation in computationally intensive fields.

Outcomes of this research include student's definition of a computational person, student's perception of their computational identity, the congruence between computational, gender, and disciplinary identities, and pedagogical approaches that enhance computational identity. This scholarship in the field of engineering education is achieved by the use of the qualitative methodology. Three different data sources were used to strengthen the interpretation of findings. These data were collected and analyzed inductively as well as deductively in order to develop a rich understanding of the students' definition of computational person, their own computational identity, and gendered interactions in computationally in projects. This research has implications for educators, students, and researchers interested in strengthening the computational identity of engineering students.

The findings of this study inform the following recommendations for educators and students to facilitate computational identity development in computationally intensive classrooms. Recommendations are also provided for engineering education researchers.

5.3.1 Implications for undergraduate engineering educators

- Arts-based education and computational education should be blended together to challenge the "nerd" and "antisocial" stereotypes of a computational person for students whose identity is in congruence with creativity and arts. In recent years, engineering education researchers have presented a new instructional model to address these needs of merging art-based education with engineering Using art processes and activities as a catalyst for both student creativity growth and interdisciplinary cooperation on issues addressing deep human needs (Laduca, Ausdenmoore, Katz-Buonincontro, Hallinan, & Marshall, 2017). Engineering instructors should incorporate pedagogical approaches, which enhance student's creativity and interest towards computation.

- Engineering education researchers investigate the effectiveness of a course by employing a discipline-based programming activity in their instructional approach. Similar to the findings of this dissertation, they reported student self-perceptions of their overall computing abilities and their abilities to solve engineering problems shifted from low to high confidence. Providing students with the opportunity to work with disciplinary/interest-based computational activities by embedding computational problems in the context of the course.

- When students worked in collaborative groups, it gives them the opportunity to understand different perspectives of computational problem solving. An emergent theme in the definition of a computational person was having a heterogeneous point of view to problem solving. Collaborative groups can help students develop this competence through engagement.

- When possible, he instructional team if more than one instructor and teaching assistants are involved, should be mixed gender and racially diverse. Each student is unique and might not benefit from the teaching strategy of a single instructor. Jessica explained having the presence of a women co-instructor helped her have a better understanding of the content. Similarly, research reports that having a female teacher provides female students with a role model and can help the women retention from school to professional career (Beyer, 2014; Friend, 2015).

- Instructors at Harvey Mudd college had success in recruiting and retaining more women (Dodds et al., 2012). The main reason for success was separating the students who had prior experience in different groups and sections. The separation not only avoids the crowding out of technical roles because of the social mediation of roles, but it also avoids comparison trap amongst peers so students with more prior exposure programming don't always get to perform or allocated computational task, which results in low self-efficacy. The findings were consistent with Harvey Mudd college study (Dodds et al., 2012). Instructors should formulate mixed gender student team where each member has a similar level of prior programming experience, to reduce the harmful comparison of prior programming experience within a group.

5.3.2 Recommendations for engineering students

Advice for students who want to foster their own computational development on how they can be at ease with computational practices.

- When women acknowledge the work of other women in computational disciplines women can feel more appreciated and this sense of recognition can improve women's computational self-efficacy. One of the interview participants Uma talked about how men readily gave recognition to one another when someone succeeded in a computational task: *"I feel like we need more women to applaud for women, you know how men do it for other men when they write a program."* She said if women to the same women can feel more appreciated and this sense of recognition can improve women's computational self-efficacy.

- Listen to others with patience, appreciating diverse opinions, and learning from each other's ideas this would help create a space with different viewpoints and ways of problem solving which are supportive learning computational and problem-solving skills from each other.

- Avoid putting down others if you disagree and show respect for everyone's ideas regardless of gender, race, class, and other makers, again this would promote tolerance to learn computational and problem-solving skills regardless of markers i.e., race and gender.

- Go beyond just academic conversations; bringing personal elements into the discussions and sharing personal life examples of persistence. Sharing personal ways of getting through computational challenges can help other peers succeed and also reduces unhealthy competition.

5.3.3 Future Research Opportunities for Engineering Education Researchers

Further research is needed to investigate the congruence between artistic and engineering identity. The disconnect may erode a student's sense of belonging, an important motivator. When students have to choose either between "the artistic" or "the technical" side of engineering, it creates an incongruence between their identities. More research on merging arts with engineering can shift the incongruence between these identities into congruence.

This dissertation investigated students' computational identity over the course of one semester. A longitudinal study that tracks students' computational identity development would provide useful insights into engineering education. This dissertation investigated only biological and agricultural and biomedical engineering students' computational identity in the context of a single thermodynamics course. A similar study that investigates students' computational identity development in other engineering disciplines where computationally intensive courses are introduced would provide useful insights into engineering education.

Additionally, the current study focused on the experiences of women. Similarly, in the current state of research, there is more literature pertaining directly to women's retention and persistence than to minorities, although many articles include a crossover. More research will be beneficial on underrepresented minorities (Black, Hispanic/Latino, Native American, Alaska Natives, Hawaiin, and other Pacific Islanders, and Asian subgroups consisting of immigrants; Ngo, 2007). Because participation patterns vary significantly between men and women within these teams, studies should disaggregate by gender. In two recent studies, researchers found that European American women were far more likely than African American, Asian, and Latinx women to implicitly equate science with males (O'Brien, Blodorn, Adams, Garcia, & Hammer, 2015). Given these findings, Student experiences of a sense of belonging operate beyond the lens of gender alone. Intersectionality (i.e., race, ethnicity, class, sexuality, age, nationality, etc.; Hills & Collins, 2016) among students and the unique oppression that results from intersectionality is an additional direction to consider. The research would help future researchers identify and highlight specific groups with low computational identity.

During this study, interview participants, only identified as belonging to a binary gender. The experiences of participants belonging to the non-binary gender can be very different, and additional research is needed to understand the computational self-efficacy of non-binary gender students as compared to women and men students. This would lead us to understand if similar pedagogies can improve computational self-efficacy levels in non-binary students.

5.4 Study Limitations

The study was limited to single-site design and restricted to participants who have persisted in the sophomore year of undergraduate engineering. The participants who were invited to take part in the current study were limited to students enrolled in a specific computationally intensive thermodynamics course. While the purpose of this study was not to generalize to a larger population, there is an acknowledgment that the sample population did not represent a diverse population. The participants who were invited to take part in the current study were limited to students who have persisted in engineering at least until the second semester of their sophomore year.

The data collection and storage plan had to move online after the midterm examination due to the COVID-19 pandemic. The face to face interviews being conducted on campus had to transition into online interviews. The semi-structured interviews conducted after March 12, 2020 were shifted to online interviews conducted through video conferencing software zoom. Seven out of twenty-three interviews were conducted and recorded through video conferencing software Zoom in the months of March and April. Additionally, the group projects supposed to be conducted after midterm were transitioned to individual projects. The data collection plan had to be modified due to social distancing guidelines.

As an increasing number of gender scholars have demonstrated, gender never operates independently of other markers of identity or dimensions of difference (i.e., race, ethnicity, class, sexuality, age, nationality, etc.; Hills & Collins, 2016), although particular contexts may make one or another of these markers more or less salient for specific individuals or groups (Hulko, 2009). Intersectionality is a recognition of the condition in which a person simultaneously has two or more social categories or social statuses (e.g., race, gender, class, sexual orientation, etc.) and the unique oppression that results from that combination (Crenshaw, 1991). Intersectionality is baked into the structure of engineering and computing; however, it was not incorporated into the research design because the current focus was to understand the interplay of gender and computational identity. However, student experiences of a sense of belonging operate beyond the lens of gender alone.

Every effort was made in this study to generate the highest level of participation while also striving to reach diverse engineering participants. Interview participants only identified belonging to binary gender self-volunteered for interviews. More women participants volunteered for interviews than men. Uneven sample sizes created analysis challenges when it came to analyze the prior experience of programming. However, reasonable efforts were taken based on interpretive data collection and analysis to reduce the negative effects of this limitation. That said, caution should be taken while attempting to generalize the results of this study to the greater engineering population because some of the findings are based on small sample sizes.

5.5 Conclusion

Engineering disciplines like biological engineering where women enjoy a good representation is adapting tools and pedagogical approaches from computer science where women representation is declining due to barriers of environment and climate, stereotypes, and self-efficacy (Cheryan, Plaut, Davies, and Steele, 2009; Vekiri and Chronaki, 2008). Research also suggests the problem of women decline in computing exists with the masculine culture that surrounds computing education (Vitores and Gil-Juárez, 2015). To affect change to promote retention in biological engineering I wanted to understand the student's computational identity in relation to gender and engineering identity. Based on the literature review conducted for this dissertation there was very limited literature available on the computational identity of engineering students which produced a research gap. A theocratical framework was assembled based on computing identity (Mahedeo et al., 2020) and social identity theory (Stryker & Burke, 2000) based on undergraduate students' recognition, interest, and performance/competence in computational activities. The dissertation fills a gap of exploring the computational identities of undergraduate engineering students who engaged in computationally intensive learning environments. The students described their own computational identity with respect to their perspective of a computational person. They also discussed experiences of gender and computational pedagogies which they perceived helped with computational identity development. The findings inform initiatives for improving engineering culture and promoting diversity in fields that are becoming computation increasingly and suffer from gender disparity.

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APPENDIX A. IRB APPROVAL

Date: 2-5-2020

IRB #: IRB-2019-748
Title: Computational thinking in Biological Engineering
Creation Date: 11-22-2019
End Date:
Status: Approved
Principal Investigator: DAVID UMULIS
Review Board: Exempt Reviewer
Sponsor: National Science Foundation - NSF, National Science Foundation - NSF

Study History

Submission Type	Initial	Review Type	Exempt	Decision	Exempt

Key Study Contacts

Member	Monica Cardella	Role	Co-Principal Investigator	Contact	mcardell@purdue.edu
Member	Aasakiran Madamanchi	Role	Co-Principal Investigator	Contact	amadaman@purdue.edu
Member	DAVID UMULIS	Role	Principal Investigator	Contact	dumulis@purdue.edu
Member	HUMA SHOAIB	Role	Primary Contact	Contact	hshoaib@purdue.edu

Initial Submission

Study Personnel

Study Personnel

In this section you will name all staff who will participate in the study.

A Principal Investigator (PI) is responsible for all aspects of a research study.
STUDENTS ARE NOT AUTHORIZED TO BE PRINCIPAL INVESTIGATORS

Provide the name of the Principal Investigator of this study.
All faculty (tenured, tenure-track, research and clinical) are eligible to be Principal Investigators. Others requesting to submit proposals as the Principal Investigator for the first time must obtain special approval.

Name: DAVID UMULIS
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Address: 225 S. University Street , West Lafayette, IN 47907-0000
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If you cannot find the name of the Purdue University personnel that you are looking for using the "Find People" button above, please list them here. We will need to verify their information and load into the system.

(First Name: Last Name: Purdue e-mail address)

Primary Contact

Provide the name of the Primary Contact of this study. The Primary Contact will be copied on all correspondence regarding the IRB review. Note that the Primary Contact and the Principal Investigator may be the same. The Primary Contact must be a current Purdue University faculty, staff, postdoc, or student and must have a role as key personnel on the study.

Name: HUMA SHOAIB
Organization: PWL ENG. EDUCATION
Address:

Phone:
Email: hshoaib@purdue.edu

If you cannot find the name of the Purdue University personnel that you are looking for using the "Find People" button above, please list them here. We will need to verify their information and load into the system.

(First Name: Last Name: Purdue e-mail address)

Key Personnel

Key personnel: The Principal Investigator and any project staff, students, postdoctoral staff, internal or external to Purdue University who contribute in a substantive way to the scientific development or execution of a project (including, but not limited to, consent, data collection or analysis).

Does your study have additional Key Personnel?

Check all that apply.

✓ Yes, I have key personnel from Purdue University

Yes, I have more key personnel from another external site (outside of Purdue).

No, the only personnel on the project are the PI and Point of Contact.

Key Personnel From Purdue University

- *The Principal Investigator and Primary Contact are considered Key Personnel. You do not need to list these names again.*
  Provide the name(s) of any other key personnel from Purdue University for this study using the "find people" button below.
  If your collaborating key personnel are not affiliated with Purdue University, please indicate this in the next section.
- *Provide the name(s) of any other key personnel from Purdue University for this study using the "find people" button below.*

- ***If your collaborating key personnel are not affiliated with Purdue University, please indicate this in the next section.***

Name: Monica Cardella
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Organization: PWL - GENERAL ADMIN
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Phone:
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If you cannot find the name of the Purdue University personnel that you are looking for using the "Find People" button above, please list them here. For researchers outside of Purdue university, please use the next section and click "external investigators".

(First Name: Last Name: Purdue e-mail address)

Provide a brief description of each person's position at Purdue (e.g. student, staff, faculty) and their role in the study.

Examples:
Prof. Principal (faculty) will oversee all aspects of the study design and conduct
John Researcher (graduate student) will recruit and consent participants and collect data
Purdue Pete (staff) will analyze collected study data.
David Umulis *(faculty) will oversee all aspects of the study design.*
Monica Cardella (faculty) will oversee all aspects of the study design.
Huma Shoaib (graduate student) will recruit and consent participants and collect data
Aasakiran Madamanchi (post-doctoral student) will analyze the collected study data.

Research Sites

Where will the study take place?

✓ Purdue University

Please check the following locations.

✓ West Lafayette

Regional Campus (PFW, PNW, IUPUI)

Polytechnic Institute Statewide Sites

Extension Sites

Please provide a brief description of the Purdue University location(s).

Provide building names, course titles, event names as applicable.

Wang Hall on Northwestern, MJIS building, Course title: ABE/BME 202 Thermodynamics

External Site (non Purdue University)

Getting started with your submission

Welcome to the submission system for the Purdue HRPP/IRB. Before you begin, you should be familiar with the framework of human research protections and how they relate to your proposed study. The materials to help you appear on our website.

Be certain that all personnel have completed online training prior to submitting the protocol.

The choices you make on the first two sections will help populate the required sections for your submission. Please look through the options and make the choice closest to your research. You can always seek assistance by scheduling an appointment with the HRPP Office or reviewing the materials at www.irb.purdue.edu.

Exempt study

Please look at the list of studies below. Determine if your proposed study design might fit into one of these descriptions.

Exempt research still requires review by the Human Research Protection Program. Choose this option if you believe your study is:

✓
- Research in a common educational setting (e.g. school, daycare) about normal educational practices.
- Educational Test, Survey, Interview, or Observation of Public Behavior
- A benign intervention involving short puzzles, games and their outcomes on human behavior conducted during a single day.
- Secondary Analysis of data, documents, records, pathological or diagnostic specimens that are publicly available or properly deidentified.
- Taste and Food Quality Evaluation or Consumer Acceptance Studies.

Please choose a category. The proper sections will populate based on your selection.

Category 1 Research conducted in established educational settings with normal education practices like:

1. *Research on regular and special education instructional strategies*
2. *Research on the effectiveness of, or the comparison, among instructional techniques, curricula, or classroom management methods*

Category 2 **Research that ONLY includes interactions through:**

- *Surveys with adults*
- ✓ *Interviews with adults*
- *Focus Groups with adults*
- *Educational Tests (cognitive, diagnostic, aptitude, achievement)*
- *Observation of public behavior*

Category 3 **Benign Behavioral Interventions.**

Interventions that are brief in duration, harmless, painless, not physically invasive, not likely to have a significant adverse lasting impact on the subjects, and the investigator has no reason to think the subjects will find the interventions offensive or embarrassing.

Category 4 **Secondary analysis of samples or data.**

NOTE: Before you will be able to submit this protocol, you will need to know the terms and conditions associated with receiving the existing data or specimens. You might also need to know the original intended use from the study's consent form. Contact the provider of the data or specimens to obtain this information before proceeding. You may also contact the Purdue IRB (irb@purdue.edu) for guidance.

Category 6 **Food and Taste Acceptance**

The research is only a taste and food acceptance quality evaluation or food consumer acceptance study

Non-exempt study

Research that does not fit into an exempt category typically involves the collection of new data from a participant.

Just-in-time

I have been contacted by a sponsor (often NSF or NIFA/USDA) to provide documentation of IRB approval, (such as Just-in-Time or JIT) but my application to the IRB is dependent on other factors such as:

- *completion of instruments*
- *prior animal studies*
- *purification of compounds*

Note: This category should be utilized ONLY if the above criteria apply. If study procedures are discernible at the time of the sponsor request, please do not select this option. The research team should affirm that their sponsor will accept documentation for a development protocol.

If you request this study type, the title of the IRB protocol must exactly match the title of the grant proposal. Most funding agencies will not accept protocols with different titles.

Quality Improvement

My research involves activities without a plan to conduct research (Case Report or Quality Improvement project)

I need to know if my project is considered "Human Subjects Research"

I would like to request that another IRB Review this study. (Request for Purdue IRB to defer to another site).

When Purdue University will be engaged in human subject research with one or more institutions, investigators may submit a Request for Deferral asking that the review be deferred to one institution's Institutional Review Board (IRB).

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When Purdue University will be engaged in human subject research with one or more institutions, investigators may submit a Request for Deferral asking that the review be deferred to one institution's Institutional Review Board (IRB).

Category Two Exemption Educational Test, Survey, Interview, or

Educational Test, Survey, Interview, or Observation of Public Behavior

Researchers are reminded that while the submission of an informed consent document is not reviewed as part of an exempt application, researchers still have an ethical obligation to ensure that participants are fully informed about the nature of a research project so that they can make an informed decision to participate

---

Confirm that your research involves the collection of information ONLY using one or more of the following:

- Surveys (not involving children)
- Interviews (not involving children)
- Focus Groups (not involving children)
- Educational Tests (cognitive, diagnostic, aptitude, achievement)
- Observation of public behavior (e.g. a public place where there would not be an expectation of privacy such as a public street or park but not a public school, a business, or a hospital)

✓ Yes

No

Which best describes the interaction(s) involved in your study?

Use of educational tests (cognitive, diagnostic, aptitude, achievement)

✓ Survey procedures

✓ Interview procedures

Focus groups

Observation of public behavior

Does the research involve children?

Yes

✓ No

Will your research project involve any visual or auditory recording?

✓ Yes

No

Please describe the audiovisual data you will collect. Detail if there will be any practices to reduce disclosure of a person's identity (facial blurring, darkened lighting, voice masking etc.)

Interviews will be audio-recorded; audio-recordings will be transcribed and immediately destroyed. The transcribed information will be kept on a password-protected computer. All identifiable information will be removed from the interview transcripts. Only the Engineering Education researcher will have access to identifiable data and will perform transcribtion (other members of the research team, who have teaching responsibilities associated with the course, will only have access to the de-identified transcripts)

Does the research require access to student education or health records?

Education records include any records held by the educational institution that contain personally identifiable information about students, including records related to an individual student?s performance, such as written or electronic records typically found in transcripts

✓ Yes

No

Identify the potential risk for harm that would occur if the security of the data was compromised.

Students' names will be removed from the surveys and replaced with a code. Interviews will be audio-recorded; audio-recordings will be immediately transcribed and destroyed. The transcripts will be saved on a password-protected computer. All identifiable information will be removed from the interview transcripts. The code key that links student names to the identifier code will be stored separately from all other study data. Only the Engineering Education researcher will have access to identifiable data (other members of the research team, who have teaching responsibilities associated with the course, will only have access to the de-identified data)

All measures will be taken so that the security of data is not harmed.

Even in the case of data theft, identifiable information won't be available.

Please describe your plans for securing data.

All answers are considered investigator assertions and are certified. Storage procedures, like all IRB protocol materials are subject to post approval monitoring at any time.

Check all that apply.

✓ Use of Purdue Box, REDCaP, Qualtrics, or other Purdue administered system.

Please describe the data storage and how this system secures the data.

Qualtrics, Online Drive (these systems are secured because they have a two way authentication key ino rder to access the data)

Paper/hard copy identifiable data and records under lock and key with controlled access to only the research team.

✓ Another electronic storage procedure.

Please describe. If necessary, upload an attachment describing data security.

---

de-identified and transcribed transcripts will be kept on shared gmail drive with access only available to team members.

Attach Data Security Plan if relevant.

ComputationalSelfefficacy-updated.docx
Post-ProjectSurvey-updated.docx
Pre-ProjectSurvey-updated.docx
InterviewProtocol-Spring2020.docx

Privacy refers to a person's desire to control access of others to themselves. Describe the steps that will be taken to protect and assure the privacy of the subject.
Detail specific actions the research team will take to ensure that privacy is protected through each phase of the study
(e.g. recruitment, mailings to subjects, phone calls with subjects, research visits).

Examples of issues:

- *Potential subjects may not want to be approached for research purposes by someone they do not know.*
- *Potential subjects may not want others to know they have a disease or were previously treated for a condition; therefore, you may want to avoid sending a recruitment letter in the mail that may be opened by others.*
- *Subjects may not want to be seen in areas that may stigmatize them or reveal a certain belief or physical/mental health condition.*

Huma Shoaib, Graduate Student Engineering Education Department. She will not participate in any grading activities or the class.

The recruitment of participants will be done through the engineering education researcher. She will do a class announcement at the end of class when instructor leaves. She would communicate that students who would want to participate in the interviews can contact her and schedule a time with her, students will be able to self volunteer by emailing the researcher if they wish to participate.

The interviews will not involve any question related to any medical diseases (mental or physical)

Will subjects receive payment or other incentives for their participation in the study?

✓ Yes

Describe the payment or incentive.

Estimate the maximum total payment. Please indicate what information you will be collecting from subjects who will be paid for their participation.

the maximum total amount will be 15$

Students will be asked questions regarding their classroom experiences and background knowledge about content and programming. The interview protocol is attached with a detailed set of open ended questions.

No

Provide a brief summary of your research

The amount of data available to inform medicine and biology is growing at an incredible rate and new technologies and methods are needed to integrate and effectively utilize the data. Bioengineering needs to produce well-trained graduates to meet future demand for experts in the field. To meet this growing need, this research program: 1) improves undergraduate Bioengineering education by changing how we teach data analysis and mathematical modeling, 2) maps the growth of students' understanding of computational concepts over time, and 3) will identify factors that lead to lower participation among women and other underrepresented minorities in these types of data and computer-focused problems. The program is designed to identify the best way to teach all aspiring bioengineers to excel at computational tasks such as how to build diagrams that connect data together or how to use a computer to make meaningful predictions based on data. Specifically, we have three objectives: (1) to characterize the progression of computational thinking in undergraduate biomedical engineering students from novice to expert over 3 courses; (2) to examine the intersection between gender, engineering identity, and computational thinking; and (3) to iteratively improve the undergraduate curricula to promote growth in computational thinking for all Bioengineers.

In order to address the objectives we seek to work on the following research questions:

-Does computational self-efficacy increase over time in students with increased exposure to computation?

-What are the trends in gender preference of technical vs non-technical roles in student groups?

-What are the least preferred group roles by the student based on student gender?

-How well students think they accomplished the role they were in? (self-belief)

- What are the meaningful computational experiences students engage in and out of classroom settings?

Exempt-Your research appears to be eligible for exemption under Category 2. You will be guided to answer just a few more items before submitting your protocol.

This exemption determination is subject to review by the HRPP Office. Please do not begin your research until you receive the final determination letter. All personnel listed in the application must complete training prior to conducting research.

Please click continue to move on to the next required sections.

Funding Source(s)

CURRENT Funding Source(s)

To review your protocol appropriately with differing sponsor standards, the HRPP must have the accurate funding source. It is a PI's responsibility to update funding sources as a modification to the protocol and associated forms when funding changes.

Please list any sources of funding that are **confirmed** by contract, agreement, or other support of a sponsor.
You will list any pending sources in the next question.

✓ Externally sponsored (federal, state, corporate, foundations, industry, donor)

Please search for the sponsor(s) here. Be certain to include any funding that originates or includes US federal sources.

If you are a student or staff member filling this out on behalf of a Principal Investigator (PI), please be certain to affirm with the PI that this information is accurate.

National Science Foundation - NSF

If you do not see the name of the funding source using the "Find Sponsors" button above, please enter the full sponsor name in the text box below.

Please use the full name of the sponsor and include any subcontracted efforts.

Internal Purdue University Departments (Includes departmental funds, start-up funds)
(Note, this does not include Purdue Research Foundation or Purdue Research Park companies-please list as external sponsor above).

None - There are no confirmed funding sources at this time.

ANTICIPATED Funding Source(s)

To review your protocol appropriately with differing sponsor standards, the HRPP must have the accurate funding source. It is a PI responsibility to update funding sources as a modification to the protocol and associated forms when funding changes.

If you are a student or staff member filling this out on behalf of a Principal Investigator (PI), please be certain to affirm with the PI that this information is accurate.

Please list any sources of funding where sponsorship is **anticipated** or pending a final decision.

✓ Externally sponsored (federal, state, corporate, foundations, industry, donor)

Please search for the sponsor(s) here. Be certain to include any funding that originates or includes US federal sources.

Provide a list of pending support for this project.

National Science Foundation - NSF

If you do not see the name of the funding source using the "Find Sponsors" button above, please enter the full sponsor name in the text box below.

Internal Purdue University Departments

(Note, this does not include Purdue Research Foundation or Purdue Research Park companies-please list as external sponsor above).

There are no pending funding sources at this time.

Conflict of Interest and Outside Activities Disclosure

Conflicts of Interest or outside activities must be disclosed and managed prior to IRB approval. For more information about these policies, please consult the resources listed in the question marks in each section.

The IRB may request confirmation of proper disclosures.

Does this IRB protocol involve any work, advice, or service for an entity other than Purdue University?

For example, if this activity is done as an outside consulting activity, or employee's start-up company, this activity will not qualify for review by the Purdue IRB and an outside IRB or service must be sought.

✓ I attest that I understand the outside activities policy and that all members of the research team are conducting this project on behalf of Purdue University.

Do you or any investigator(s) participating in this study have a significant financial interest (SFI) related to this research project?

Receiving more than $5,000 in compensation from, or having ownership interests in, outside entities, constitute Significant Financial Interests that need to be disclosed. Definitions of SFI, Investigator and Institutional Responsibilities, can be found at https://www.purdue.edu/policies/ethics/iiib2.html#definitions.

Yes

✓ No

Do you or any person affiliated with the protocol have or know of any arrangement or understanding, tentative or final, relating to any future financial interest, financial relationship, future grant, position, or advisory role either related to the protocol, or dependent on the outcome of the research under the protocol?

Yes

✓ No

Is there anything not disclosed above which you believe might constitute a conflict of interest or an appearance of a conflict of interest in connection with the protocol?

Yes

✓ No

APPENDIX B. INTERVIEW RECRUITMENT FLYER

Computational Thinking in Biological Engineering

SEEKING VOLUNTEERS FOR A RESEARCH STUDY

The purpose of this research study is to examine the development computational identity and understand classroom experiences of computation and group work of students participating in ABE 202 during Spring 2020.

To participate in this research, you must:

- Be a Purdue student enrolled in ABE 202 during Spring 2020.
- Be 16 years old or older.

Participation in this study involves:

- A time commitment of 1 hour for the interview [Audio Recorded Interviews]
- Paid compensation of 15 USD per interview

To find out more information about this study or schedule an interview, please contact Huma Shoaib at:

- Email: hshoaib@purdue.edu

Research Study: *Computational Thinking in Biological Engineering*
Contact: Huma Shoaib
Email: hshoaib@purdue.edu

Research Study: *Computational Thinking in Biological Engineering* **Contact:** Huma Shoaib **Email: hshoaib@purdue.edu**
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Research Study: *Computational Thinking in Biological Engineering* **Contact:** Huma Shoaib **Email: hshoaib@purdue.edu**

APPENDIX C. COURSE SYLLABUS

ABE 202 / BME 295 Thermodynamics Syllabus 2020.
Course # 18743 for ABE. # 10199 For BME.
Tuesday and Thursday 9:00-10:15 AM
1097 MJIS

Course Personnel

Instructors: Associate Professor U (deidentified)
Office Hours: Tues 3:30-4:30 PM

Assistant Professor P (deidentified)
Office Hours: Thurs 3:00-4:00 PM

Graduate TA: Office hours will be in 1080 MJIS
Deidentified

Course research staff
Bobby Madamanchi
Huma Shoaib

Description

The major objective for this course is to understand and exploit basic principles of thermodynamics as they apply to biological systems and biological processes. Specifically, the course will focus on biological processes across scales: from the nanometer scale of biomolecules, the micrometer scale of cells, the millimeter and meter scales of tissues and organisms, all the way up to the 100+ meter scale for bioprocess equipment and industry-scale production. The course can be loosely classified into two parts: (i) guiding principles and fundamental equations for thermodynamics in biological and biomedical engineering, and (ii) applications of engineering principles to the study of cellular and molecular systems.
Successful completion of the course will enable students to meet the following learning objectives:

- Understand basic principles of Mass, Energy, and Entropy balance equations to macro scale thermodynamic processes (SO 1, 6, 7)
- Apply the following concepts to solve problems in the biological engineering and biomedical engineering disciplines (SO 1, 6, 7)
  - First & Second Law of Thermodynamics
  - Open vs closed systems
  - Balances of mass, heat, work, and entropy/energy flow
  - Reversibility/irreversibility
  - Path dependence/independence

- Apply micro- and nano scale thermodynamics to cells and systems of cells (SO 1, 3, 6, 7)
- Gain knowledge of main factors that determine numerical values of physical chemical properties associated with bioprocesses. (SO 7)
- Derive thermodynamic properties for biomolecules including derivation using statistical mechanical approaches. (SO 3, 5)
- Solve multiphysics and multi-scale problems for thermodynamic processes using the computer. (SO 1, 2, 5, 7)

Additionally, students will benefit in the following ways:

- Students will develop the attitudinal dimensions of computational thinking (SO 2)
    - Confidence in dealing with complexity
    - Persistence in working with difficult problems
    - Tolerance for ambiguity
    - The ability to deal with open ended problems
    - The ability to communicate and work with others to achieve a common goal or solution
- Students will gain experience in working with non-linear systems and systems away from equilibrium (SO 1, 6)
- Students will gain experience in working with teams to solve complex modeling tasks (SO 5)

How does this class differ from last year and why?

Change	Reason
More teamwork	▪ This is a critical skill in the modern workplace
More computation	▪ Biological and biomedical engineering are increasingly computationally intensive fields ▪ Computation allows us to investigate systems away from equilibrium o more applicable to real world problems
More active-learning	▪ Evidence suggest that this leads to deeper understanding

How will computation be used in this class? What if I don't know how to code?

This course uses Jupyter Notebooks, an open-source web application that provides an interactive online environment for computing. What this means is that in each lecture you'll get a link to an online worksheet that will contain the lecture notes as well as the computing exercises for that class period.

All computing exercises are in python. However, in the first half of the semester all the computing exercises are going to be tightly related to the provided examples. You will be doing things like modifying an example script to change the inputs or to add new variables to a system of equations.

Later in the semester, as you become more familiar with the Jupyter notebook environment, you will be asked to develop models from scratch, but by that point you will have many examples to draw upon. We do not anticipate that python coding will be a source of difficulty in this class but if it is, we will provide the resources to help you through this hurdle.

We strongly encourage you to bring a laptop or tablet to this class. If you do not own or a laptop or tablet, please let me know and we can make arrangements to facilitate your class participation/learning.

How will active learning work in the classroom?

- Modeling activities in which you will iteratively develop predictions/hypotheses about how systems work and then compare your predictions to data from computational models. In these exercises you will iteratively refine your understanding of thermodynamics principles and develop intuition about the function of thermodynamics systems.
- Turn-to-your partner in class exercises where you solve problems in 4-5 person groups

Class-based research

This course is the product of funded design-based research. We are continuously examining our teaching practices to see how we can provide the most educational value to our students. To support this process, we will be observing the classroom and qualitatively examining classroom materials produced in this course. All data and observations from this course will be de-identified to respect student privacy. Consent forms that will allow you to opt-in or opt-out of data collection, will be administered before any classroom observation or materials collection. Your classroom experience and your grade will not be affected in any way.

Class Policies

Academic honesty All students are expected to perform with the highest academic integrity. Students are expected to abide by the Purdue University Code of Honor and Regulations regarding student conduct. The bottom-line is DON'T CHEAT, and DON'T HELP OTHERS CHEAT. The source of the following two excerpts can be found at: http://www.purdue.edu/univregs/pages/stu_conduct/stu_regulations.html

Part 5: Section II- Purdue University Code of Honor: "To foster a climate of trust and high standards of academic achievement, Purdue University is committed to cultivating academic integrity and expects students to exhibit the highest standards of honor in their scholastic endeavors. Academic integrity is essential to the success of Purdue University's mission. As members of the academic community, our foremost interest is toward achieving noble educational goals and our foremost responsibility is to ensure that academic honesty prevails."

Part 5: Section III Regulations Governing Student Conduct, Disciplinary Proceedings, and Appeals "Misconduct Subject to Disciplinary Penalties. The following actions constitute misconduct for which students may be subject to administrative action or disciplinary penalties. Dishonesty in connection with any University activity. Cheating, plagiarism, or knowingly furnishing false information to the University are examples of dishonesty. The commitment of the acts of cheating, lying, stealing, and deceit in any of their diverse forms (such as the use of ghost-written papers, the use of substitutes for taking examinations, the use of illegal cribs, plagiarism, and copying during examinations) is dishonest and must not be tolerated. Moreover, knowingly to aid and abet, directly or indirectly, other parties in committing dishonest acts is in itself dishonest. (University Senate Document 72-18, December 15, 1972)."

Campus emergency

Campus emergencies might include the following: classroom accidents, hazardous chemical releases/spills, fires, weather emergencies and natural disasters, violence, and pandemic. In the event of a major campus emergency, class will be cancelled and will only resume under notification by the instructor. In the event of a major campus emergency, course requirements, deadlines and grading percentages are subject to changes that may be necessitated by a revised semester calendar or other circumstances.

Grading breakdown

Classroom participation 10%
Projects 30%
Midterm exam 1 15%
Midterm exam 2 15%
Final exam 30%

Grade Ranges

Grade	GPA Value	Range
A+,A	4.0	93-100
A-	3.7	90.0-92.9
B+	3.3	87.0-89.9
B	3.0	83.0-86.9
B-	2.7	80.0-82.9
C+	2.3	77.0-79.9
C	2.0	73.0-76.9
C-	1.7	70.0-72.9
D+	1.3	67.0-69.9
D	1.0	63.0-66.9
D-	0.7	60.0-62.9
F	0.0	<60.0

NOTE: The scale can change per instructor discretion so that a given grade may fall into a lower bin range (i.e. A, A+ could drop down to 83-90) if the instructor deems it necessary. Under no circumstances will the reverse occur.

Concept Schedule

Week 1 (Jan 14 & 16): Course Introduction and Scientific Computing Introduction

- Introductions & Syllabus Review
- Thermodynamics & Computation Pre-assessment
- Pre-Project1 Survey
- Introduction to Scientific Computing with Python
    - Defining Variables
    - Plotting
    - For Loops
    - Defining Functions

Week 2 (Jan 21 & 23): Rate Constants & Quantitative Analysis

- **Team Project (Can you outrun a dinosaur?)**
- Intrinsic vs Extrinsic Properties.
- Half-life Calculation

Week 3 (Jan 28 & 30): Differential Mass Balance Analysis of Chemical Reactions

- Fundamental Theorem of Calculus
- Using Stochiometric Equivalents to model the progress of chemical reactions.
- Understanding and applying Euler Method to solve mass balance reactions under dynamic conditions.

Week 4 (Feb 4 & 6): Mass Balance Modeling of Biological Systems

- Introduction to information transfer in biological systems (signal transduction)
- Models of transcriptional Gene Regulation (Hill Function)
- Modeling information flow via Mass Balance Equations
- **Team Project (Toxin Project)**

Week 5 (Feb 11 & 13): Applying Energy Balance Equations to Chemical, Biological & Biomedical Systems

- A special focus on understanding Heat vs Temperature and developing an intuition around the first law of thermodynamics.
- Solving systems at both the molecular and industrial scale, using both analytic approaches and numerical approaches.
- Work.
- Specific Heat.

Week 6 (Feb 18 & 20) Review & Exam 1

Week 7 (Feb 25 & 27): Introduction to Entropy

- 2nd Law of Thermodynamics
- Using Entropy balance equations in conjunction with mass balance and energy balance equations to solve problems in chemical, biological, and biomedical engineering applications.
    - Parallel & Countercurrent Flow

Week 8 (March 3 & 5): Heat Cycle

- Heat Pump and Cycle
- Magic Refrigerator

Spring Break

Week 9 (March 10 &12): Vapor-Liquid Equilibria & Fugacity

- Van Der Waal's Equations of State
- Peng – Robinson Equations of State

Week 10 (March 22 & 24): Modeling Project: Reactor Systems

- Multi-stable states
- **Individual Project** (Bilius & Amundsun Chemical Reactor Stability & Sensitivity)

Week 11 (March 31 & April 2): Thermodynamic Limits of Cellular Behavior

- Gibbs Free Energy

Week 11 (April 7 & 9): Thermodynamic Limits of Cellular Behavior II

- Heat Conduction

Week 12 (April 14 & 16): Review & Exam 2

Unit 3 – Capstone

Week 13 (April 21 & 23): Diffusion

- Brownian motion & Diffusion

Week 14 (April 28 & 30): Modeling Project (Biological Diffusion)

- **Final Exam** (Finite Difference Modeling of Diffusion in Biological Systems)

APPENDIX D. CLASS OBSERVATION PROTOCOL

Date	
Location on campus	
Start Time	
End Time	
Class Number	

Type of session: Coding session/ Lecture Session/ Combined
Topic
Participants (other than students)
Pre class or Initial Observations
Class Session Time Stamping
Student Direction
Tone of the instructor
What do I see going on here (How is what is going on here similar to, or different from, other incidents or events recorded)?

Perceived Binary Gender Make-Up of Groups (updated as students came in late)

Table Number	Number of Men	Number of Women	Observer Comments

APPENDIX E. INTERVIEW PROTOCOL

Interview Protocol for Identity, Computation, and Gender Experiences

Opening statements

Thank you for agreeing to participate in the study. I am a graduate student in Engineering Education, and I am studying the student experiences about computation, identity and gender in the thermodynamics classroom.

Identity

Background

- What experiences brought you to engineering? (interest)
- What has been your experience as an engineering student?

    (ask them about good and bad experiences)
    Can you tell something about the Engineering culture around you?

Present

- Do you engage with your peers in and out of class? – What is most challenging?
- Who is a computational person? /How would you define a computational person?
- Do you see/describe yourself as a computational person?
- How do you see this course contribution to this computational identity? (in case yes or partial)
- Do you believe you can do well in computational activities? (performance)
- Which skills and competencies do you believe are essential to have as an engineering student?

Future Self

- Can you talk about your future aspirations?
- What will it mean for you to be a computational person? (interest)
- Do you view yourself as a professional engineer?

- Which skills and competencies do you perceive are essential as a professional engineering? (competence)

Recognition

Can you talk about how your peers and instructors view you as an engineering student?

Computation

- What skills do you think are essential in your field of study?
    - Follow up – why do you think this “xyz” skill is important?
- Do you use programming concepts in your BME classes?
- How comfortable are you with programming or computational activities? – yes, why
- What previous experience did you had with programming before taking this class?
- What kind of new challenges are you facing with programming this semester?
- Does your group or peers help you when you are performing a computational task?
- How do view the role of computation in professional engineering?
- Can you tell me about your experience of working on computational activities? (these activities can be from formal or informal settings)

Group Work

- Tell me about your class group peers? Are they the same peers you work with in every class?
- Tell me about your role in the group?
- Tell me more how you work with your group?
- Tell me about how your peers view you in the group?
- Which member do you believe is more helpful and why?

Persistence

- You talked about when you faced challenge while you were engaged in the computational experience…. Why did you keep going when it got really tough? (What motivated you? What tools or coping methods did you use to keep you from quitting?)
- Who were your peers as your worked through this process?

- What has been the biggest obstacle you've overcome as an engineering student?
- Give an example of a time when you had difficulty balancing your personal and work objectives. What did you do?
- What motivates you to keep working through the computational task?

Conclusion

- Do you have any other thoughts on you being a "xyz-gender" in a discipline which is becoming more and more computational with time?

APPENDIX F. PRE-COURSE PROJECT SURVEY

Q1 What is your full name?

____

Q2 What is your most preferred role/position in the project? Rank in order of most preferred to least preferred

______ Project Leader (1)

______ Project Manager (2)

______ Communications/Spokesperson (3)

______ Strategy Analyst (4)

______ Technical Leader (5)

Q3 What is the reason for the selection of your first three most preferred roles? Comment Please

____

____

____

Q4

What are your learning goals – things you hope to achieve through completion of this project? (i.e. you might have a goal of improving your coding skills or your communication skills)

____

____

____

Q5 How comfortable are you with your ability to perform computational modeling?

- ◯ Extremely comfortable (1)
- ◯ Somewhat comfortable (2)
- ◯ Neither comfortable nor uncomfortable (3)
- ◯ Somewhat uncomfortable (4)
- ◯ Extremely uncomfortable (5)

Q6 How comfortable are you with thermodynamics content in this unit?

- ◯ Extremely comfortable (1)
- ◯ Somewhat comfortable (2)
- ◯ Neither comfortable nor uncomfortable (3)
- ◯ Somewhat uncomfortable (4)
- ◯ Extremely uncomfortable (5)

APPENDIX G. CODE BOOK

In vivo Description	Initial Codes	Secondary Codes	Description	Construct
"Well, I like to do things on time, and I am very organized I cannot wait 'til last day to get things done, so I like to stay on top of things"	• Preference: working individually • Perception of self: organized • Perception of self: not a procrastinator	Self-perception or recognition	How an individual view one's own behavior	Deductive code Recognition (Garcia et al. 2019/ Mahadeo et al. 2020)
		Perceive or recognize others	How an individual views other individuals' behavior	
" I'm bored of programming; I feel like it's the same thing over and over again there is other stuff that I want to do, and I want to try out " "So, you know normally I am a very lazy, procrastinator person. But it depends on my interest if I want to be efficient or not. So sometimes yeah, I am a computational person other times no I'm good, you can do it yourself."	• Boredom from programming • Perception of self: lazy, procrastinator	Interest	How much attentiveness or not an individual show towards computational activities like programming or mathematical modeling.	Deductive code Interest (Garcia et al. 2019/ Mahadeo et al. 2020)
"In the last project I was the technical lead and I have just had good experience with coding in the past so I can sit down, and I can think with a flow rather than just not know what I'm doing."	• Good experience with coding • Experience: Succeeding in programming • Solution/Goal oriented thinking	Programming Proficiency (Yes/No)	Belief in ability to translate a mathematical problem or equation to a computer program	Deductive code Performance/ Competence (Garcia et al. 2019/ Mahadeo et al. 2020)

"I would say computational person is somebody who is probably good at math and by being good at math they're probably good at logic and they're very focused on getting the calculations right."	• Perception of others: Good at mathematics • Logical proficiency/thinking	Mathematics skills or mathematical modelling (Yes/No)	Ability to create a mathematical model of a given problem statement, or mentions proficiency in logic and reasoning	
"Being able to think through the possible ways to solve a problem that haven't been tried yet is definitely a strength I have"	• Thinks through multiple solutions • Finds effective solution • Adapts different ways to solve problems	Problem solving ability (Yes/No)	overcomes errors and able to completely solve the problem	
"a computational person has ability of decision making based on weighing pros and cons of different decisions and then going with the least damaging decision I guess when I think of a computational person, I think of someone who I wouldn't say just think things through, but like think things logically and when it comes to making decisions, they weigh their options in a logical way as sort of like statistical way."	• Perception of others: Good at comparison • Logical comparisons • Considers option	Decision Maker	Description, definition, or perception of a computational person provided by the student.	Computational person (inductive)

“I was put with a girl and then this guy. And he was trying to take over and do all the code and he was not letting us do anything, right? one time, like I was saying like, Oh, you should do this and this. And I gave him a suggestion. He was like, no, no, no, no, no, no, that is not going to work. And then five minutes later he said, Oh, I should have done it, dah, dah, dah. And it was the exact thing that I had told him, so I said that's what I told you. And he was like, well, whatever. And he did this so many times…… I mean we got good grades, but did it make me feel better? Did it make me feel good? No. Not because he wasn't listening to like what I was saying? And the worst part is like he wouldn't even say, Oh, you were right. I should have done this. He would say, Oh, I can't believe, I didn't think of this.”	• Toxic masculinity • Experience of Sexist interactions • Feelings non acknowledgement/ rejection • feelings of dis-comfort and non-belonging	Unequal task sorting among gender	Experiences which result in unequal division of computational labor (idea acceptance or tasks allocation amongst genders)	Lived Experiences of gender and computation (inductive)

“*In the beginning of the course I felt kind of uncomfortable with like even just the structure given, but now I definitely feel like totally fine with being given the structure, but I think I could start to transition to not having the structure now.*”	• Structure of the code helps with programming • Transition to code without structure	Change in Comfort level with programming	Participant describes a comparative trend/transition in comfort or confidence level with computer programming activities from the course.	Confidence Increase/Decrease (inductive)
“if I get stuck when I'm coding something well that's fun part. And then usually I'll like maybe like put the code away for like a little bit like 30 minutes or an hour and like go to something else and then try and come back to it, see if I can remember.”	• Acting with patience • Attempting again / giving another try • Attitude: Accepts challenges	Not giving up	Staying motivated and determined to complete the problem, homework, programming task.	Persistence (inductive)
“I am a creative person, so you know I don’t follow things in a very logical manner, I am half creative half computational person”	• Self-perception: Creative or artistic identity • Creative/artistic Person	Disassociation between logical and creative self	Depicting an association/disassociation with another identity in relation to computational identity	Congruent/ Incongruent (inductive)
“I think the technical aspect might come in girls leaving this discipline, because maybe a lot of girls have like grown up thinking like math is not something, they're supposed to be good at or can be good at.”	• Perception of others: women have doubt on math ability • Women not good at math’s	Women/Feminine stereotype	A thought about how specific types of individuals behave or can behave	Stereotypes (inductive)

APPENDIX H. TEAM ROLES DESCRIPTION

The Project Leader: is responsible for the overall operation and effectiveness of the team and provides planning, direction, and guidance. He/she ensures that the project needs are met by the efficient and timely completion of deliverables in a high-quality manner. He/she is responsible for managing the team's resources, including documentation, Shared drive management, use of meeting and design time, people, and materials. The Project Leader oversees the management and delivery of projects to which she/he is assigned. She/he is responsible for the definition and execution of the project plans including project initiation, planning, execution, controlling and closing out of the project.

The Project Manager/Design Engineer is responsible for making sure that the team is documenting the work being done throughout the project. More directly, the project manager takes a big picture approach of the design constraints, decision making processes, and design implementations for each process to ensure smooth transitions of the project to future team members, graduate teaching assistants, faculty advisor, and project partners. As the project manager you will ensure that your team's design document captures the challenges your team faced, the decisions your team made and the actions that resulted in enough depth that someone outside of your team could understand and make use of the work that you have done. The project manager should not only capture what was done by the team, but also the reasoning behind why it was done.

The Technical lead: Technical lead oversee a team of personnel focused on technical issues, including software development, and engineering tasks. provides on and off-site technical support. Responsible for simulation and testing of the computational model. Responsible for development of effective program and supervising system modifications. Technical leads must have excellent programming language abilities in order to successfully perform their job responsibilities.

The Spokesperson: Presents the group's ideas to the rest of the class and faculty. Oversees and manages all communication between the team and the project partner and other stakeholders. She/he ensures that the project partner is kept informed on a regular basis of the progress of the team and that relevant team documentation is delivered to the project partner for observation or comment. Communicates updates from the team regarding changes to workflow, design, or progress. manages project dependencies and project team and stakeholder relationships as it relates to the project and ensures timely and effective communication with the team leader and the entire team.

The Strategy Analyst: Observes team dynamics and guides the consensus-building process (helps group members come to a common conclusion). Identify, aggregate, and analyze data to provide a successful problem-solving strategy within the given costs/budget. Provide analytical support in the planning, designing, due diligence, and implementation of solution.

VITA

EDUCATION

PhD. | Engineering Education *12//2020*

Purdue University, West Lafayette, IN

Dissertation: Understanding Computational Identity Development in Undergraduate students participating in a Thermodynamics Course

Master of Computer Science | Data Science and Computer Vision *08/2015*

Punjab University, Lahore, Pakistan

Thesis: Sentiment Analysis of Images

Bachelor of Science | Computer Science and Software Engineering *11/2013*

Forman Christian College, Lahore, Pakistan

PROFESSIONAL EXPERIENCE

GRADUATE RESEARCH ASSISTANT *08/2018 to CURRENT*

Purdue University | West Lafayette, IN

- Researched information regarding engineering education to assist professors with academic pursuits.
- Supported biomedical engineering department with academic research design.
- Prepared literature for reports, presentations or submission to peer-review journals.
- Performed statistical, qualitative and quantitative analysis.
- Provided comprehensive research assistance and support when designing and executing protocols.

GRADUATE RESEARCH ASSISTANT *08/2019 to 05/2020*

Purdue University | West Lafayette, IN

- Researched information regarding engineering education to assist professors with academic pursuits.
- Supported biomedical engineering department with academic research design.
- Prepared literature for reports, presentations or submission to peer-review journals.
- Performed statistical, qualitative and quantitative analysis.
- Provided comprehensive research assistance and support when designing and executing protocols.

MENTOR *08/2016 to 05/2018*

Purdue University | West Lafayette, IN

- Provided one on one mentoring to two graduate PhD students that increased their writing and research abilities.
- Provided guidance and recommended best practices to ensure research productivity.

LECTURER, COMPUTER SCIENCE *05/2015 to 05/2016*

Kinnaird College for Women | Lahore, Pakistan

- Developed semester outlines and instructional plans for each class session to comply with stated course objectives.
- Delivered engaging curriculum through diverse methods, including classroom instruction, computer lab activities and online learning systems.
- Taught digital logic design, artificial intelligence, and computer programming fundamentals.
- Oversaw undergraduate student projects and advised on focus, methodology and report generation to meet preset standards.

VISITING LECTURER *08/2015 to 03/2016*

Punjab University | Lahore, Pakistan

- Evaluated and revised lesson plans and course content to facilitate and moderate classroom discussions and student-centered learning.
- Taught diverse student population by employing various learning styles and abilities.
- Hired and trained Six Teaching Assistants for grading and classroom administration.
- Taught digital logic design, discrete mathematics, and object-oriented programming.

GRADUATE TEACHING ASSISTANT

Information Technology University | Lahore, Pakistan

- Mentored students through office hours and one-on-one communication.
- Conducted research in computer vision with team of eight graduates and faculty.
- Directed students in performing and completing assigned tasks.

PUBLICATIONS

Conference publications

1. Shoaib, H., *A systematized literature review of student learning, participation, and engagement in engineering massive open online courses*. In: American Society of engineering education virtual Conference, June, 21-24, 2020.
2. Shoaib, H., Brophy, S., *A systematic literature-based perspective towards learning and pedagogy of Computational Thinking*. In: American Society of engineering education virtual Conference, June, 21-24, 2020.
3. Shoaib, H., Cardella, M., Gender bias in purchase of STEM toys (A comparative study). In: American Society of engineering education virtual Conference, June, 21-24, 2020.
4. Shoaib, H., Cardella, M., Madamanchi, A., & Umulis, D. *An investigation of undergraduates' computational thinking in a sophomore-level biomedical engineering course.* Proceedings of the Annual IEEE Frontiers in Education Conference, October 16-19, 2019. Cincinnati, OH.
5. Shoaib, H., Cardella, M., Madamanchi, A., & Umulis, D. Computation, gender, and engineering identity among biomedical engineering undergraduates. Proceedings of the Annual IEEE Frontiers in Education Conference, October 16-19, 2019. Cincinnati, OH.
6. Shoaib, H., Jaffry, S. W., A Survey of Augmented Reality. In: Proceedings of XIII International Conference on Virtual and Augmented Reality (ICVAR 2015), Singapore, January, 8-9, 2015.

Manuscript in progress or submitted for publication

1. Shoaib, H., Cardella, M., Madamanchi, A., Umulis, D. & Pienaar E (2020). Understanding the Gender Gap in Computational Self Efficacy by Exploring Undergraduate Students' Meaning Making in A Computationally Intensive Thermodynamics Course. Manuscript submitted for publication.
2. Shoaib, H., Cardella, M., Madamanchi, A., & Umulis, D. (2020) I think I am getting there" understanding the computational identity of engineering students participating in a computationally intensive thermodynamics course. Manuscript submitted for publication.