

Physics students develop professional identity throughout their  
undergraduate programs and after graduation

by

Hien Khong

B.S., Ho Chi Minh University of Pedagogy, Vietnam, 2016

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AN ABSTRACT OF A DISSERTATION

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Department of Physics  
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# Abstract

College has traditionally been regarded as a critical period of time for students to develop their scientific knowledge and skills in order to be prepared for a career. This thesis investigates the impact of three overarching components throughout the undergraduate physics program on students' identity development of physics undergraduate students: physics laboratories, sense of belonging, and future career development. The first component focuses on upper-division students' interactions in the advanced physics laboratory to form equitable or inequitable collaboration. The second component investigates students' sense of belonging to their departments, which is impacted by their perceptions of departmental features. The final component involves students imagining their future professional selves and the interaction of future selves with past selves. The sum of these three overarching components provides a comprehensive picture of students' needs and issues that must be addressed in order to advocate for a meaningful physics program for all students. In this dissertation, each overarching component will be presented as a separate project.

The first project investigates the dynamics of group work in mixed-gender groups of three physics students. Two theoretical constructs are used to characterize dynamics of students' interactions: perceived expertise and inchargeness. We hypothesize that the distribution of positionings within these constructs will have an effect on equity, which is defined as everyone having a fair opportunity to access on-task discussion and experimental equipment. Observing three groups of students working on X-ray diffraction and torsional oscillation, the study found that members with high perceived expertise tend to use their confidence in discourse to direct others' behaviors and the group's activities. Group members with more perceived expertise and inchargeness have full access to on-task discussions and laboratory equipment. Conversely, the students with lower perceived expertise and inchargeness can have either full or limited access to on-task discussions and equipment. Their access depends

on how the students with higher perceived expertise and inchargeness facilitate the group activities. Findings from this study suggests noticing these dynamics in the classroom and work to increase fair access to all students.

The second project highlights students' perceptions of departmental features that can support or inhibit students' sense of belonging (SB). Double-majored students are selected from the data cohort to explore their sense of belonging in four departments: physics, education, math, and computer science (CS). Situating the project into the Community of Practice Framework, features of departmental communities of practice are identified that can support or diminish mutual engagement, which is defined as activities that members participate in together to build connections and relationships. Theoretically, the greater the mutual engagement between departmental members, the more likely it is that members will shift toward central membership, resulting in a strong SB in the department. The project conducted semi-structured interviews and multiple case studies to identify a set of departmental features that can impact a SB: collaboration, extracurricular activities, future career supports, and building structure. We conclude that if the four departmental features are perceived to foster the mutual engagement between students and faculty as well as among students, students are more likely to develop the central membership in the department, thereby increasing a SB. In contrast, if departmental features are perceived to be less accessible for students to form mutual engagement, students' central membership is less likely to develop, sequentially lowering students' SB. The study's implications include departmental suggestions for improving students' SB, resulting in a more inclusive learning environment for all students.

The last project is situated within Possible Selves Theory to explore senior students and recent alumni in STEM envisioning future professional identity after college. Longitudinal semi-structured interviews at a large urban university in the United States were conducted to ask participants about their career plans and resources they needed to develop future possible selves. This study presents multiple case studies of four physics students exploring, adjusting, and refining their future possible selves. Overall, all case studies express well-elaborated future possible selves constructed by integrating academic and sociocultural experiences. In

particular, positive academic experiences from courses, research, and conferences enhance students' interest and self-efficacy in a discipline/field, resulting in constructing future possible selves in the field. However, consistent with prior study, negative experiences such as not being valued by peers can reduce students' self-efficacy, sequentially sabotaging students' possible selves in the field. Personality, living habits, and social identity are also incorporated in order to make future selves congruent with sociocultural experiences. Furthermore, analyzing students' narratives about futures also reveals two primary possible selves paths: a path of narrowing and refining imagined future; and a path of trying new selves in series.

The findings from the three projects provide an understanding of students' dynamics in physics classrooms, as well as students' needs throughout their undergraduate programs to develop a sense of belonging and a professional identity. These insights can then be translated into implications for administrators and faculty to consider in order to create a campus environment that encourages students to progress through their undergraduate studies and into their professional lives.

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# Dedication

*To my parents without whom this thesis would never have been completed*

AND

*In memory of my oldest sister*

# Chapter 1

## Introduction

This thesis focuses on the development of students' professional identities, beginning in a physics classroom and progressing through the undergraduate curriculum. Given a growing demand for workforce in science, technology, engineering, mathematics (STEM) in the U.S in the last few decades,<sup>1;2</sup> one major goal of academic institutions and undergraduate curriculum is to create the pathways for career preparation for students to gain entry into professional life.<sup>3;4</sup> In order to achieve this goal, research has called attention to helping students develop professional identity and engaging them in Professional Development Engagement (PDE). According to Blau et al.,<sup>3</sup> PDE - defined as "the level of undergraduate engagement in professional development" - needs to reflect on career-related activities for "life after college" and should be viewed as an important component of students' education, whereas professional identity only can be developed when a student becomes technically competent, self-confident, and experiences a sense of belonging to the professional community.<sup>5</sup> As a result, over the last decade, education researchers have expanded the scope from teaching content knowledge to designing and improving undergraduate curricula that embrace the goal of developing students' professional identity.<sup>6</sup>

In response to the need for professional identity development for students, numerous studies have begun to investigate the effectiveness of both academic and extracurricular activities in developing students' identities. A large body of literature, for example, has

consistently found that engaging students in authentic science research work can increase not only content knowledge but also skills outside of the classroom, employability, and motivation to enter science careers.<sup>7-10</sup> Informal physics programs<sup>11;12</sup> and internships<sup>4</sup> also provide opportunities for professional development, strengthening students' commitment to their degrees and broadening their career options.

Despite many positive outcomes in supporting students' identity, there are still many challenges to overcome, especially in physics as a field and as a community, putting a significant strain on students' professional identity development. Until now, physics has remained the least welcoming and diverse field for women and minorities.<sup>13-15</sup> According to a national data study conducted in 2016, women's interest in physics has been consistently low over the last four decades, and aspirations to become a research scientist are on the decline.<sup>15</sup> The unwelcoming climate in physics has caused a tremendous threat of who can do, pursue, and belong to physics. A large body of research in physics education has demonstrated this threat by students leaving the field,<sup>15</sup> as well as a disparity in sense of belonging,<sup>16-18</sup> self-efficacy,<sup>19</sup> interest,<sup>19</sup> and classroom engagement<sup>20</sup> among different demographic groups of students. Thus, there is an urgent need for physics as a field to reflect on practices and the overall climate to ensure students are best supported in their personal and professional growth.<sup>6</sup>

This thesis, therefore, sheds light on features of physics undergraduate programs to investigate the extent to which students are supported in developing their professional identity throughout their undergraduate programs and after graduation. The undergraduate program includes a diverse range of components, including physics courses (both lectures and laboratories), undergraduate research, independent studies, and extracurricular and career-related activities. This thesis particularly looks into three overarching components that can significantly impact students' professional identity: physics labs; sense of belonging; and future career development.

The following content of this thesis is arranged in the line of these three parts. Physics labs are presented in chapter 2. The chapter investigates students' interactions while working in a group in an advanced physics lab. Based on the interactions of upper-division students,

a model of equity and inequity for group work in physics labs is discovered. The study's findings suggest implementations for instructional practices that can help improve equity in a physics classroom.

Going beyond the physics classrooms is students' development outside the classroom, starting from students' sense of belonging to future career development. These two overarching components, namely, a sense of belonging and future career development, are discussed in chapters 3, 4, and 5. Chapter 3 presents the context and data collection for these two studies. Chapter 4 emphasizes the importance of departmental belonging and the need for additional research to improve students' sense of belonging in their departments. Throughout the chapter, the findings of departmental features that can foster or hinder students' belonging are presented. Findings from the study implement some takeaways to improve the current undergraduate program, with the goal of increasing students' sense of belonging.

Chapter 5 presents a study investigating how undergraduate students develop their professional careers and identity. We begin with a review of the literature on students' career development, emphasizing the importance of understanding the process that students use to refine and advance their professional goals. The study also identifies students' future expectations and perceived barriers while thinking about futures. The study's implementations shed light on how career-related activities should be facilitated to meet the needs of students.

Chapter 6 summarizes all findings from three overarching components: physics labs; senses of belonging; and future career development, and discusses the future work to continue supporting undergraduate students' professional identity development.

# Chapter 2

## Equitable interactions in upper-division physics lab groups

Interactions between students in advanced physics laboratory groups can encourage or inhibit student learning depending on group dynamics. This chapter uses the theoretical perspective of positioning to characterize the dynamics of an advanced physics group work in the light of two positionings: perceived expertise and inchargeness. We examine the extent to which the perceived expertise and inchargeness distribution affects equity, which is defined as everyone having a fair opportunity to access on-task discussions and experimental equipment. Overall, members with high perceived expertise tend to use their confident discourses to direct others' behaviors and the group's activities. Besides, members with higher perceived expertise and inchargeness have full access to on-task discussions and laboratory equipment. Conversely, the students with lower perceived expertise and inchargeness can have either full or limited access to on-task discussions and equipment. Their access depends on how the students with higher perceived expertise and inchargeness facilitate the group dynamics. We suggest how instructors could notice these dynamics in the classroom and work to increase fair access to all.

## 2.1 Introduction

The purpose of this chapter is to investigate the dynamics of group work that can shape or inhibit equity in advanced physics laboratories. Despite calls to increase diversity, equity, and inclusion in Science, Technology, Engineering and Mathematics (STEM), physics has remained the least diverse and least equitable field for women and underrepresented groups.<sup>13–15</sup> The unwelcoming climate in physics has been demonstrated not only by students leaving the field,<sup>14;21–26</sup> but also by a gap in grades,<sup>27–33</sup> self-efficacy,<sup>34–37</sup> sense of belonging,<sup>36;38</sup> interest,<sup>35</sup> and verbal participation<sup>39</sup> between different demographic groups of students. Such gaps put physics in jeopardy as a field that favors a specific group of people over an equitable learning environment for all students.

Inequity in physics also seeps into laboratories. Lab sessions are intended to enhance students' learning.<sup>40–45</sup> Women in labs, however, are hampered in developing physics identities due to the specific roles that are usually assigned to them, such as secretarial roles, who spend more time on managerial or note-taking tasks, whereas opportunities to tinker with the apparatus are more often granted to men.<sup>43;46</sup> Despite the fact that women and men have similar preferences for experimentation roles in physics labs,<sup>47</sup> the old notion of who performs what persists.<sup>46</sup>

This chapter attempts to determine the extent to which the group work of three students (mixed gender) in an advanced physics labs is equitable. The positioning theory forms the theoretical basis for this research.<sup>48</sup> The theory is epistemologically placed within the social constructivism realm<sup>49</sup> and proposing discursive ontology,<sup>50</sup> implying that knowledge emerges from social interactions with others in a group. While interacting to construct knowledge, individuals position themselves in relation to others based on norms and conventions (discourses) regarding how they are spoken. This process results in positioning, e.g., who is more or less capable of contributing to the joint work, raising the possibility that some students learn more than others.<sup>51–56</sup> Guided by the theoretical perspectives of positioning, this chapter determines how students position themselves in relation to peers while interacting to conduct a physics experiment, and how such positioning affects the formation

of equity in an advanced physics lab.

We first define equity as a condition in which everyone has a fair opportunity to access the learning materials.<sup>57</sup> We then observe the students' interactions to determine students' positionings in the lens of two constructs: perceived expertise and inchargeness. Students are positioned as having perceived expertise are those who provide firm statements or strong disagreement. Students are positioned as having inchargeness are those who direct the group's activities (more details in Sec. 2.3). The analysis shows that these two positionings impact the extent to which students can have full access to the learning materials. This work extends the discussion about social positionings and equity from introductory physics<sup>58-60</sup> to a scope of an advanced physics lab, allowing for the implementation of instructional practices to build up an equitable learning environment for all students.

## 2.2 Operationalizing equity

While equity and equality are frequently used interchangeably in research, there is a distinction between them. Equity implies that students should have access to all resources needed to ensure fairness and justice, whereas equality ensures that students have equal access to resources.<sup>57;61</sup> Regardless of the distinction, many studies look into equality as a first step to understand equity.

A large body of previous studies has borrowed the concept of social positionings (e.g., power, authority, intellectual status, perceived ability, and perceived popularity)<sup>52;56;61-66</sup> to highlight the unequal participation among students in group work. Early research showed that students with higher academic and social status in group work had greater access to their materials and higher levels of engagement in collaborative work than their middle and low-status counterparts. They also showed greater control of group sessions, whereas low status students behaved passively.<sup>52;67;68</sup> Furthermore, students who spoke more learned more.<sup>52</sup> Some scholars also suggested that in a group work, equity could not be achieved unless there was equal number of turns of talk, or time spent using equipment (i.e., 50-50).<sup>66;69;70</sup>

In the context of physics college courses, the most commonly used metric for determining

equity is “equity for equal potential,” which means that there should be an equal amount of learning from different gender and racial groups to ascertain equity.<sup>71</sup> This metric has been used in prior work to draw conclusions about equity by comparing student outcomes such as final score or posttest,<sup>27;29–33;72–76</sup> verbal participation,<sup>39</sup> or psychological gain (self-efficacy,<sup>36;37;74;77</sup> sense of belonging,<sup>36;38</sup> interest<sup>35</sup>).

In physics labs, equity is conceptualized in the lens of role divisions. Despite students preferring the idea a “fair share” division and having similar preference of roles in labs,<sup>47;78</sup> researchers have found that students in mixed-gender labs groups engage in gendered task division. Women, for instance, are attached to some specific roles that spend more time on managerial tasks while less time on operating apparatus and recording data, resulting in little growth in physics identity.<sup>43;79</sup> Holmes et al. stated that the decision of who will take control over apparatus in a group might be informed by gender.<sup>46</sup>

The operationalization of equity in physics labs has recently been modeled by participationist and positionings perspectives,<sup>58</sup> viewing learning is an ontological process of engaging in the sociocultural practices of physics. According to Brookes et al., “if knowledge is a process of knowing, the way in which students participate in that process becomes paramount” (p.2).<sup>58</sup> Under this view, students participate in sociocultural practices by dynamically positioning themselves in relation to others based on how they speak. Furthermore, the way they speak will determine whether their ideas are heard and accepted by peers.<sup>80</sup> Equity in a group work can thus be achieved only when everyone’s voice is heard and acknowledged.<sup>47;58–60</sup> It was discovered that when every idea is taken up by the group, the group becomes more effective at completing challenging physics activities.<sup>58</sup>

These viewpoints serve as a theoretical inspiration for the current research. We are guided by the positioning theory in accordance with prior studies<sup>58–60</sup> to believe that students position themselves in relation to others while interacting. The positioning of each member is implied by the student’s discourses and has a potential to increase or decrease learning opportunities for others in the group.<sup>57</sup> This work attempts to look into such positionings to examine the extent to which positionings can support or inhibit equitable learning in group work. The following sections go over two of the positionings: perceived expertise and

inchargeness, as well as the model of equity used in this chapter.

## 2.3 Theoretical background

### 2.3.1 Positioning theory

As mentioned earlier, this work follows the concept of positioning theory to construe the dynamics of students' interactions in a group work.<sup>48;81</sup> Positioning theory is a social constructionist approach<sup>50</sup> that characterizes interactions between individuals in an intergroup discussion, focusing on how people use words, norms, and conventions to define who they are in the eyes of other members.<sup>80;82;83</sup> Based on the discursive patterns in their talk, people are labeled with certain rights, duties to speak, and obligations. These right, duties, and obligations set the basis for constructing interpersonal positions and positioning.<sup>48</sup> Positionings, as opposed to roles, are more dynamic and can change over time depending on their moment-by-moment discourses.

Examining how positionings affect students' learning has received a lot of attention in education research, with different position lenses such as power, authority, expertise, and perceived popularity.<sup>52;56;61–66</sup> This chapter focuses on two positionings: perceived expertise and inchargeness. Both of these positionings are rooted from positioning theory. As perceived expertise and inchargeness have been recently explored in the setting of an introductory physics lab,<sup>58–60;84</sup> we broaden the scope to determine how these positionings play out in an advanced physics lab.

#### Perceived expertise

One may define expertise associated with the level of disciplined knowledge of professionals as actual expertise.<sup>85;86</sup> In a psychological study, perceived expertise is not the same as actual expertise. Perceived expertise is closely related to the extent of talking and confidence while actual expertise is not.<sup>86</sup> Another key feature of perceived expertise is that it is socially formed through discussion and evaluation by other members.<sup>86–88</sup>

This chapter examines how students gain perceived expertise by conversing in a social construct, namely an advanced physics lab group. We adopt findings from Brookes et al. to characterize perceived expertise through the quality of members' discourses.<sup>58;84</sup> A member who is positioned as having perceived expertise provides an idea or answers a question in a "firm" manner using downward inflection. Expert, in this case, is associated with "firm statements of fact or firm or strong disagreement" (p.5).<sup>58</sup> Some examples of firm statement are "they are the same thing," "they both collide" (downward inflection). A member who has lower perceived expertise softens the statements and uses hedges to reduce the assertion of arguments such as "they are the same thing, right?" (upward inflection), "I think they probably collide" (using hedges). A member who is perceived as having the lowest expertise, on the other hand, often agrees with an explanation without providing any other information, or "can ask a question or make a statement that suggests some degree of helplessness or lack of knowledge" (p.5)<sup>58</sup> such as "How do I do this?", "I don't know what to do," "I am confused." These features of perceived expertise are consistent with claims made by Littlepage et al. that perceived expertise is a social construct that is closely related to confidence and the extent of talking.<sup>86</sup>

## **Inchargeness**

Inchargeness describes the position of who controls or directs the flow of group activities.<sup>89;90</sup> A member with high inchargeness tends to successfully steer the conversation by choosing who speaks next or what to do next. Ideas presented by persons with high inchargeness are more likely to be taken up by peers than those with low inchargeness.

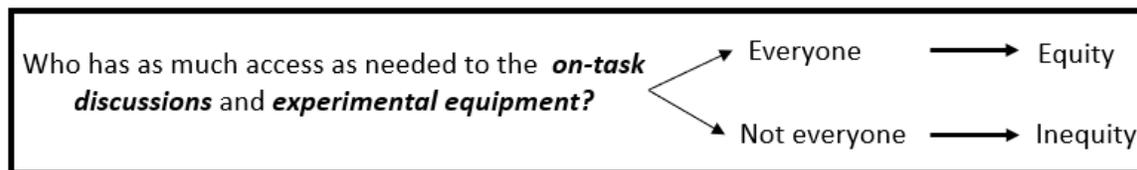
The Inchargeness framework proposes behavioral markers through which distribution of inchargeness is identified in a conversation, such as who proposes, sets, or limits the topics of conversation or types of discourse. Employing this framework to the physics lab context, inchargeness is rated by using following behavioral markers: who tells peers what to do; who decides what to do next. High inchargeness is verified when commands or decisions are taken up and followed by members of the group.

Perceived expertise and inchargeness share some similar features. Both are rooted from the positioning theory, thus they both imply positionings emerged from group interactions and dynamically vary over time depending on how they talk and behave. Members can be positioned as having perceived expertise and inchargeness on different tasks, or one member can be positioned as having high perceived expertise and inchargeness across the entire collaboration. The difference between these two positions is that perceived expertise implies assertiveness and confidence in speaking, whereas inchargeness implies degrees of controlling and directing the behaviors of others. Members who use downward inflection in their discourse (higher perceived expertise) are not always the ones commanding others and controlling group activities (high inchargeness). Members who speak with assertiveness and confidence, on the other hand, may control group activity. This study, in particular, sheds light on such dynamics in the context of advanced physics.

### 2.3.2 Equity

We employ Esmonde's definition to define equity as a condition in which everyone has a fair opportunity to access learning materials.<sup>57</sup> In the context of prior research, learning materials are a conversational floor where two or more people enter into a joint endeavor.<sup>61;63</sup> In the context of advanced physics labs, experiments are more complicated than in introductory levels and require students to engage simultaneously in both sophisticated reasoning and apparatus.<sup>91</sup> Thus, two aspects for learning materials are considered: (i) on-task discussion - a conversational floor when students join a mutual conversation about the concept of the experiment, and (ii) experimental equipment - where students get hands on with the apparatus to conduct the experiment. From the definition of equity and perspectives of learning materials in advanced physics labs, Fig. 2.1 summarizes a model of equity used in this work. A group is equitable when everyone in the group has as much access as needed to on-going discussions and experimental equipment. While engaging in the on-going discussions and experimental equipment, students' ideas should be taken up and acknowledged by group members to verify equity (references<sup>47;58-60</sup>). In contrast, inequity emerges if access of a

member is limited, blocked, or controlled by others.



**Figure 2.1:** *The ways in which equity or inequity can emerge from a physics group work*

When incorporating social positioning into an examination of equity, there have been mixed results. To ensure equity, some research showed that incharge-ness should be distributed equally.<sup>89:90</sup> Some argued that this isn't always the case, as long as the person who is in charge ensures that everyone is heard and acknowledged.<sup>59</sup> In line with incharge-ness, a member who primarily maintains the expert position can either threaten the learning of others or facilitate to ensure the equity in group. However, if two members are positioned as experts, they cannot speak with one voice and work independently on the group work, leading to inequity.<sup>84</sup> These findings reflect the intricacies of group dynamics and suggest there is no single criterion for determining equity. This chapter seeks to extend this discussion of equity and social positionings by addressing two research questions:

1. How are perceived expertise and incharge-ness distributed in advanced physics laboratory groups?
2. To what extent does the distribution of incharge-ness and perceived expertise explain equity in group work?

## 2.4 Context and Methodology

Participants in this study were undergraduate students in an advanced physics laboratory at a public research university in the United States. Students met twice a week, and worked in groups of two or three. Each meeting lasted for three hours and it typically took students two to three meetings to finish each experiment. Each meeting was video recorded.

We present three case studies of students conducting experiments. Multiple case studies are an effective qualitative research methodology for comparing and contrasting different aspects of a phenomenon as experienced by different individuals, in this case, groups.<sup>92</sup> The first episode focused on Charlie, Abbey, and Will as they worked on the second day of an X-ray diffraction experiment. Because one member, Abbey, was absent on the first day, the second day was chosen. The second and third case studies were Shaun, Claire, and Jared working on a torsional oscillator experiment and the X-ray diffraction, respectively. We purposefully chose one experiment (X-ray diffraction) conducted by two different groups to investigate whether the structure of the experiment itself affects equity.<sup>57;61;93</sup> We also chose these two groups on purpose because they frequently spoke and interacted with one another during the experiments.

The X-ray diffraction and torsional oscillator experiments are two classic physics experiments. In the X-ray diffraction, students need to determine the characteristic of the intensity emitted by an X-ray tube. These emitted X-rays are used to identify the structure and parameters for several crystal samples such as NaCl or Al. There is a wide range of activities associated with this experiment such as operating the X-ray tube, controlling accelerating voltage and filament current, entering angles, maximum angles, step resolutions into the computer, and changes the crystals. The torsional oscillator, similar to the spring-mass system, undergoes harmonic motion. By the time we observed the experiment, the group was conducting the underdamped oscillation experiment, trying to fit data to measure the frequency of the damped oscillation ( $\omega$ ) and the damping constant ( $\gamma$ ) to obtain the relationship  $\omega^2 + \gamma^2/4 = \omega_0^2$ , which students need to compare the calculated undamped frequency  $\omega_0$  with the theoretical value derived by the torsion constant and the moment of inertia of the rotor.

Our analyses focused on the first 60 minutes of videos that we observed (see Tab.2.1 for the data corpus). This period of time provided us with the richest data as students were in the phase of exploring the concept of the experiment and apparatus setup. Three researchers began the analyses by watching the video recordings to become acquainted with the data and developing preliminary observations of students' positionings.

**Table 2.1:** *Focused data corpus*

Group	Experiment	Day
Charlie, Will, Abbey	X-ray	2
Shaun, Claire, Jared	X-ray	1
Shaun, Claire, Jared	Torsional oscillator	1

We did look into a brief segment (2-minute segment) to determine the positionings of group members by averaging across all 2-minute segments. However, moment-to-moment did not provide us with reliable evidence to rate inchargeness and perceived expertise. Students, within 2 minutes, were randomly switching between on tasks (experimenting) and off tasks (chatting, laughing, joking, going outside, long silence). Thus, social positionings did not become apparent in such a short segment, rather they emerged across the collaboration over time. For this reason, we re-conducted our analysis from a holistic viewpoint instead of segment-based average, that is re-watching the video recordings and looking for as many clues as we could to qualitatively infer perceived expertise and inchargeness during the first 60 minutes. In each experiment, three researchers reached an agreement on each member’s positioning.

We resumed our preliminary analysis and incorporated it into our post analysis. We transcribed episodes where we clearly received clues to rate positionings. We used the framework presented in Sec. 2.3.1 to rate perceived expertise. During the analysis, we used the following technical terms interchangeably: “firm discourses/statements,” “confident discourses/statements,” “speaking with firmness or confidence,” and “using downward inflections” to refer to members with high perceived expertise. Because perceived expertise was positioned dynamically and meant to vary from moment to moment, we did not expect a member with high perceived expertise to always use downward inflections but never express confusion. Indeed, the distribution of perceived expertise was based on the trend that was most frequently observed during the first 60 minutes. For example, if a member consistently appeared to have more confidence in their statements than confusions, we assigned high overall perceived expertise rating to that member.

We rated high inchargeness based on two main markers: commanding peers’ behaviors;

and making decisions when/what to do next. A member with low incharge-ness frequently took up and complied with the commands, and did not get involved in the decision-making process. Incharge-ness, like perceived expertise, can change from moment to moment. We used the same timescale to rate relative levels of incharge-ness as we did for perceived expertise.

Observing students' interactions provided us clues to judge the group equity (Fig. 2.1). Students have access to the on-task discussions when they enter, join the mutual discussions without interruptions from peers, and have their ideas acknowledged by group members. Students have access to the experimental equipment when they can approach, touch, facilitate, and work on it as they wish without having to wait for permission from peers. If two members frequently form a subgroup to discuss the on-task questions, the third member is deemed to not have access to the on-task discussion. A student who needs permissions from peers to work on equipment is considered as not having a fair access to the equipment.

In the following section, we provide evident episodes that enabled us to draw incharge-ness and perceived expertise in each group. It's worth noting that we didn't count (e.g., how many times the student used downward inflections in his/her discourses to have high perceived expertise) to rate positionings. As previously stated, the examination of 2-minute segments did not provide reliable data to do so. As a result, we can only provide a holistic trend in students' discourses drawn from some representative episodes to illustrate the findings.

## 2.5 Perceived expertise and incharge-ness

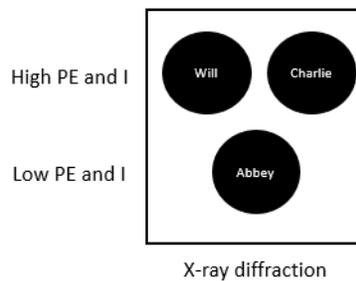
Perceived expertise and incharge-ness were initially intended to be two distinct positionings of group interactions. We assume, for example, that those who make firm and confident statements are not always the ones commanding and directing the activities of the group, and those in charge do not necessarily speak with downward inflections or confidence. However, no such patterns were apparently observed in our analysis. Indeed, these two positionings were intertwined and mutually entangled in a way that members with high perceived expertise in the group tended to use downward inflection and firm discourses to control peer's

behaviors and direct the group's activity.

### 2.5.1 X-ray diffraction (Charlie, Abbey, and Will)



**Figure 2.2:** *Abbey (sitting right in front of the X-ray box, Charlie (in the middle), and Will (standing near Charlie)*



**Figure 2.3:** *Distribution of social positionings. The PE and I correspond to the perceived expertise and inchargeness, respectively*

The first case study presents a group of three students on the second day conducting an X-ray diffraction: Abbey, Charlie, and Will (see Fig. 2.2). Abbey missed the first day of the lab but returned the next day. While Will and Charlie had figured out how to operate the X-ray box and moved to data collection, Abbey was baffled by what her classmates had done the day before. The distribution of the group's social positions is depicted in Fig. 2.3. We present some episodes in which the distribution of the group's social positions were evidently emerged.

## Perceived expertise

The group's dynamics were divided. Will and Charlie formed a subgroup to interact with each other on a regular basis. As evidenced in the excerpt below, they took turns asking questions (using upward inflections) and providing information for each other with downward inflection (underlined statements). This interactive pattern between Will and Charlie relatively remained consistent across the 60 minutes. We assigned them the same level of perceived expertise.

Will: Why is this step on?

Charlie: Because we never took it off. It was trying to calibrate but it was not.

Will: Do you want me to turn it back on?

Charlie: No no no no no.

Will (mimicking Charlie): No no no no no.

Charlie: No no no no no. It is calibrating. Okay. Do you wanna ask her about the split?

Will: I think so.

Charlie: Is it not touching?

Will: No. It is just going around the circle.

Charlie: Can we connect this? With which are we on?

Will: We're on 34.

In contrast, Abbey throughout the experiment frequently expressed her confusion and lack of knowledge. Her absence on the first day left her perplexed about what was going on. We compiled Abbey's statements that suggested degrees of helplessness and confusion, positioning her as lowest expertise in relation to Will and Charlie: "Do you guys wanna do a quick review on what you've been doing?", "And then we just read the stuff from the computer?", "What are we going to do today?", "What are we doing?", "I have no idea what we are doing, so if you want to practice explaining it, I'd love to hear."

In response to Abbey's confusion, both Will and Charlie showed confidence and firmness in providing information to Abbey. When Abbey asked for a quick review, Charlie responded:

“Right now we are calibrating,” Will continued: “This shoots X-ray that hits the crystal, this is the step motor, this piece of tape stops if it goes through the traffic, don’t do that.” “Yeah, because it will detect the black tape, so you have to stop,” Charlie added. We rated high perceived expertise for Will and Charlie, and low for Abbey due to the difference in level of confidence and firmness in discourse between Will-Charlie and Abbey.

### **Inchargeness**

Will and Charlie both directed the group’s activities and controlled Abbey’s behaviors, leaving them with higher inchargeness than Abbey. For instance, after 50 minutes, Charlie turned to Will and asked: “Switch the crystal? Do we have another crystal?” Both Will and Charlie were immediately involved in the crystal-changing task, and they decided to switch from NaCl to fluorescent, leaving Abbey out of the task. Abbey’s questions - “What are we doing now?”, “What do we need to do?”, “Which is crystal then?” - indicated that she did not have a control over the flow of group’s activity. We also noticed that while changing the crystal together, Will and Charlie did not always respond to Abbey’s questions.

Not only that, Abbey’ behaviors were directed by her peers. The following excerpt is one of many moments that Will and Charlie used downward inflection to command Abbey (italicized statements). Abbey took up and carried out commands, positioning her peers with higher inchargeness.

Charlie (to Abbey): *Alright, you can start the X-rays, and I will start acquiring the data.*

Abbey: So I start now?

Charlie: yeah

Charlie: *Hold on.*

Abbey: Am I doing wrong?

Will: *Make sure it gets on the back.*

A question asked by Abbey (“Am I doing wrong?”) showed the low confidence in her knowl-

edge and the need of her peer's directions. Across 60 minutes, Abbey neither commanded Will and Charier nor decided what to do next. Instead, Charlie assigned Abbey some simple tasks such as turning on or turning off the switch, but these tasks were still under Charlie's control. Altogether, we conclude that Charlie and Will had about equal inchargeness but higher than Abbey's.

Putting together, Will and Charlie behaved equally to each other. In which, they took turns to ask and confidently answer questions to each other; and decided the flow of the experiment together. In contrast, Abbey's absence on the first day might explain her lack of knowledge on the ongoing experiment. Her discourses throughout the experiment suggested degrees of helplessness and confusion (lowest perceived expertise). Will and Charlie, on the other hand, tended to use downward inflections and firmness to direct Abbey's behaviors.

### 2.5.2 Torsional oscillator (Shaun, Claire, and Jared)

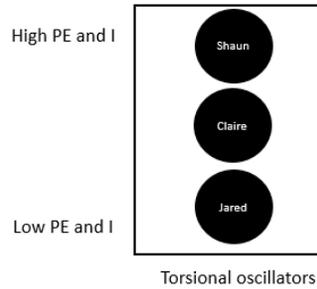
The second case study is a group of three students: Shaun, Claire and Jared working on a torsional oscillator experiment (see Fig. 2.4). We present some episodes that evidently showed social positionings of members as shown in Fig. 2.5.



**Figure 2.4:** *From left to right: Shaun, Claire, and Jared*

#### Perceived expertise

Shaun demonstrated his perceived expertise in most of this group's discussions by firmly and confidently providing information to Claire and Shaun. The following excerpt is an example of Shaun using downward inflection (underlined statements) to propose a strategy



**Figure 2.5:** *Distribution of social positionings*

to measure  $\omega_0$  in various ways and then compare the results.

Shaun: What we are going to do here, we measure this B and C, and we plot these, and these will give us frequency omega. The equation found is...

Claire (overlapping): B squared plus C squared equals omega squared.

(In the lab manual,  $B^2$  referred to  $\gamma^2/4$ , and  $C^2$  referred to  $\omega^2$ , omega squared mentioned by students was meant  $\omega_0^2$ )

Shaun: What we can do is we measured omega already in different ways.

Claire: Yeah.

Jared: Okay.

Shaun: We measure another omega, and then we can compare those values.

Jared: So what is the equation to find omega? B square plus C square equals omega squared?

Claire (to Jared): Yes.

Shaun (to Jared, overlapping with Claire): Uhm.

Jared: We got B from a spreadsheet?

Claire and Jared (at the same time): Yep.

In response to Shaun, Claire and Jared quickly agree without further arguments such as “Okay,” “Yeah.” Across the collaboration, Shaun frequently speaks with firmness to deliver his ideas to both Claire and Jared. For this reason, we assigned highest perceived expertise for Shaun.

Claire's perceived expertise was higher than Jared's in the preceding episode. Although both Claire and Jared mostly received information from Shaun, Claire did confidently provide the equation for the group ("B squared plus C squared equals omega squared") and confirm Jared's question. Jared, while expressing less confusion than Abbey, did not provide any information to his peers; he was more of an information receiver in the group. For these reasons, we rated Claire as having lower perceived expertise than Shaun but higher than Jared.

### **Inchargeness**

Shaun was in charge of the majority of the group's activities. Shaun, for example, decided that the group should move to the experimental setup and told Jared, "What we need to do now is get the fan spin up." "All right," Jared said. Jared stood up and began working on the apparatus after Shaun's decision. The task of setting up the apparatus, however, was under Shaun's control, with Shaun directing Jared's actions on how and what to do, as shown in the following episode.

Shaun: We need to set up like page 32 at the bottom, what we need to do is we need to set it up.

Jared: Ok.

Shaun: There are strings on sides like this with the masses hanging on from the pulleys, so we can hang more masses.

Jared: Okay.

Shaun: So I guess we can use these strings (Shaun is giving Jared a string), the key is gonna be at the right level.

Jared: What do you mean?

Shaun: The string can't be like this, it has to be like that (doing body language to describe the setup to Jared).

Jared: Okay, be straight.

Shaun: It has to be touching that, it has to go over the pulley.

Shaun's statements are not exact commands because he used "we" instead of "you." However, these statements were still intended to tell Jared what to do and how to do it. Jared responded to the instruction with "Ok," promoting Shaun's position as having higher incharge-ness than Jared. Noticing the quality of Shaun's discourse, he consistently used downward inflections to direct Jared's behaviors.

Claire, on the other hand, was in charge of determining the frequency of the oscillation by plotting the graph. Her actions, however, were under Shaun's control. We observed Shaun commanded Claire many times, such as "plot this to see what kind of plot that is," "go back to that one," "next," "just take the final time and divide by three," "square the magnitude," and "add them together and take derivatives." We didn't see Claire rejecting Shaun's commands; instead, she took up and did what Shaun told her to do, indicating that Shaun had more incharge-ness than Claire. Once again, Shaun's statements revealed his perceived expertise, as he used a firm tone to direct Claire's actions.

We didn't see much interaction between Claire and Jared because they were both focused on different tasks. Claire, on the other hand, took command and directed Jared's actions once they were on the same task. Claire assigned Jared the task of operating the oscilloscope in the episode below (*italicized statements*). Again, we noticed that Claire mostly used downward inflection to command Jared. Jared took up and obeyed Claire's orders. Jared's statement "tell me what to do, I'll do it" indicated that Jared was willing to be directed by his peers, leaving him with the least incharge-ness. Overall, we conclude that Claire is more in charge than Jared but less than Shaun.

Jared (to the whole group): Tell me what to do, I will do it.

Claire (to Jared): *Shift it again.*

Claire: Channel 2, here is channel 1, can we zoom in each channel?

Jared: Can we do that?

Claire: hmm... (Claire closely approached the oscilloscope to give it a try)

Jared: Do we use the change of time or...

Claire: *Use voltage.*

Jared: Okay. Do you want me to make it bigger?

Claire: Yeah

Jared: I think you have to use “change the time.”

Claire: *right. Try it again.*

In short, similar to Will and Charlie, Shaun used his confident and firm discourses to direct the group’s activity. Claire exhibited the same phenomenon when she turned to Jared but showed less expertise and inchargeness when she interacted with Shaun. Jared, like Abbey, was more of a information receiver, lacking confidence in discourses and willing to be directed by peers. Compare between Abbey and Jared, Abbey’s absence might explain the high degree of confusion through her discourses (“I have no idea what we are doing,” for example, whereas we did not see such confusion in Jared’s discourses.) Additionally, the sameness in positionings between Abbey and Jared suggests that within these two groups, gender does not account for who is more likely to be in the lowest positionings in a mixed-gender group work.

### **2.5.3 X-ray diffraction (Shaun, Claire, and Jared)**

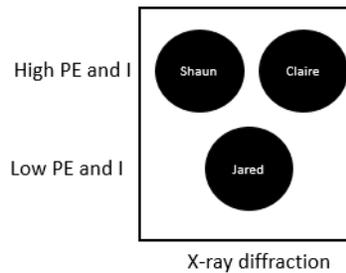
We present the third case study where the group of three students, Shaun, Claire, and Jared switched to X-rays (see Fig. 2.6). Throughout the first hour, the group was constantly struggling with the experiment’s concepts and setup. They were unsure how to use the X-ray machine, control the accelerating voltage, and insert the crystals. The majority of the time, the group remained silent, appeared frustrated, and sought assistance from students in other groups, TAs, and the instructor. We assemble some episodes in which we can clearly rate the group’s social positionings (see Fig. 2.7).

#### **Perceived expertise**

In the episode below, both Claire and Jared were confused about the notation of angle  $2\theta$ , the angle between the incoming and the scattering beam. Jared turned to Shaun after a few



**Figure 2.6:** *Shaun is sitting in the middle, Jared is to the right, and Claire is sitting opposite Jared*



**Figure 2.7:** *Distribution of social positionings*

minutes and asked, “What is the angle theta minus two?” The group discussion revealed Shaun’ perceived expertise where he confidently provided explanations and disagreements (underlined statements). Claire and Jared responded by agreeing with Shaun without further argument. This episode positioned Shaun with higher expertise than his peers.

Jared: What is the angle theta minus two?

Shaun: When this thing rotates an angle theta, the angle (making hand gestures), because the crystal rotates too.

Jared: Okay.

Claire: Why is theta minus two?

Shaun: It is two thetas. When you go with angel theta, angles between reflection, reflected twice.

Claire: So what is theta minus two theta, why are we subtracting two thetas?

Shaun: It is not minus two thetas.

Claire: Ohhh.

Jared: It is like one to five, one dash five I think (with the “hedging” tone).

Shaun: No.

Jared: Okay

(Shaun approached the board and started writing to continue explaining.)

However, when the group moved to data collection, Claire started showing her expertise. In the episode below, seeing Shaun and Jared were struggling with the computer, Claire confidently intervened to present her experiences with computer. Statements or denials (underlined) made by Claire provided information for the group to start the calibration. The question she posed to her peers (“What is it asking for?”) was not intended to elicit information for herself, but rather to instruct her peers on what to do next. The group, therefore, relied on Claire’s computational skills to progress the experiment.

Shaun (to Jared): You need to “go to maximum.”

Jared (to Shaun): Where?

Shaun (to Jared): Didn’t you do that last time?

Claire: No. (inaudible)

Jared (to Shaun): No, we do something over here. Can I get out of here? (Jared was confused with the software.)

Claire (to Jared): Cancel. Click cancel again.

Claire: What is it asking for?

Jared (to Claire): Maximum angel.

Claire: Click ok, type something in, try it again.

Jared (to Claire): Ok, calibrate?

Claire: Yeah.

Shaun (to Jared): Go to max, can you click the button right there?

Claire: No, last time it was literally just moved.

We conclude that Shaun and Claire took turns to be perceived as having expertise on different tasks. While Shaun confidently presented his understanding towards concepts of the experiment, Claire showed her confidence in computational tasks. Jared, like torsional

oscillator experiment, relied on his peers to gain information, leaving him the lowest perceived expertise.

### **Inchargeness**

Shaun and Claire took turns directing the activities of the group. Because the group was constantly struggling with the experiment, there were times when members became frustrated with the X-ray tube and the computer. In both of these cases, Shaun and Claire took the initiative to seek assistance and troubleshoot. Claire directed computer-related activities to collect data while Shaun continued to provide ideas to progress the experiment.

Shaun: We need to turn this one on, let's allow the X-ray to warm up for 5 minutes before turning on the voltage.

Claire: It said there is nothing back here.

Jared: Yeah, there is a key and power right here (pointing at the X-ray tube.)

Shaun: We need to hook it up.

Shaun (to Jared): *Right here, Jared* (giving Jared the cord to plug in the power supply).

Claire (to Jared): *Put it in and then turn it on.*

In this episode, Shaun decided what to do next (“We need to turn it on,” “We need to hook it up.”) Both Shaun and Claire used the firm tone to command Jared to plug the cord into the power supply to turn on the X-ray box (italicized statements). Jared took up the commands. However, the group did not succeed and quickly fell into silence. After a while, Claire again stood up and called the TA for help. Following the instruction by the TA, Claire successfully inserted the crystal into the holder and got the experiment started.

We consistently observed Shaun provided ideas to progress the experiment (“We need to turn it on,” “We need to set this one up,” “We need to put the step motor back,” “We need to calibrate it now.”) The group took up Shaun’s idea to progress the experiment. When the group turned to computer-related tasks, Claire controlled the activity as shown in the episode below.

Jared (to Shaun) : Oh what you need to do is to go to mins.

Claire: Yeah, it is what I am thinking.

Claire (to Shaun): *Pull it this way.*

(Shaun took up and did it)

Claire (to Jared): *Try it again.*

(After this, she came up to Jared's space to take over the computer and continue the calibration).

Claire was constantly switching between calibrating the X-ray box and using the computer. She called TA several times for assistance, worked on crystal replacement, and ran numerous calibration trials on the computer. When things didn't go as planned, Shaun and Claire both asked questions and sought assistance from the TA. Overall, we conclude that Shaun and Claire were relatively equal in charge, while Jared was the least in charge of the group.

In comparison to the previous two case studies, we found that members with high in-chargeness often used firm discourses (downward inflection) to direct peers' behaviors and group activity. In the torsional oscillator, Shaun used firm discourses to direct Claire's behavior; in the X-ray diffraction, Claire used firm discourses to direct Shaun's behavior. This occurrence resembles Will and Charlie's treatment of Abbey in the first case study. Furthermore, while the similarity in positionings between Abbey and Jared suggests that gender does not account for low positionings, Claire's increased expertise and in-chargeness in the X-ray diffraction shows that gender has no impact on who is likely to gain positionings in mixed-gender group work.

## 2.6 Equity

This section illustrates which group is equitable using the model proposed in Fig. 2.1. Our judgement of equity was based on our observations while rating students' positionings. If all members are included, freely join the on-task discussion and experimental equipment, and

ideas/questions are heard by peers, we conclude the group is equitable.

### **2.6.1 Equity is based on access to the on-task discussion**

A subgroup to discuss the experiment formed between Will and Charlie limited Abbey's access to the on-task discussion. Will and Charlie, for example, discussed "question three" in the lab manual without including Abbey. Abbey (who was excluded) had to overhear Will and Charlie's conversation to catch up on her own. "Oh, we're already here, aren't we?", "Is this where we're at?" Abbey asked, pointing to her lab manual. This scene demonstrates how Will and Charlie excluded Abbey from their discussions. We also noticed that Abbey's questions were not always heard when Will and Charlie were working on a separate task together. A Will-Charlie subgroup and Abbey's confusion across the experiment illustrate the blocked access for Abbey to engage with the on-going discussion.

In contrast, Shaun, Claire and Jared all participated in the on-going discussion. For example, in the torsional oscillator, Shaun and Claire were discussing the function of the plot, Shaun inclusively involved Jared ("Does it make sense, Jared?", "Jared, see what is going on.") Another time when Claire was in the discussion with TA, Shaun and Jared were setting up the experiment, Jared was able to engage in back and forth between two activities: setting up apparatus with Shaun and asking questions with TA. In this group, there was no sign of forming a subgroup and excluding another. Everyone could intervene the on-going discussion to ask questions, and their questions were heard and addressed by others.

### **2.6.2 Equity is based on access to the experimental equipment**

Abbey had limited access to the equipment. Will and Charlie took turns controlling the experimental space. Abbey was allowed to touch the equipment, but only for small and simple tasks such as turning on the switch, as instructed by Charlie. When the group moved on to more difficult tasks, for example, changing the sample or operating the computer to calibrate, Will and Charlie worked together without Abbey.

Unlike Abbey, Jared was given the entire experimental space to explore and work on as

much as he needed, particularly in the torsional oscillator, where Shaun assigned Jared to set up the experiment. When Shaun found that Jared's setup was incorrect, he and Jared worked together to troubleshoot the system. Instead of being passively engaged in simple tasks, the collaboration provided Jared with opportunities to learn alongside Shaun. Here's an episode from Shaun and Jared's collaboration on the apparatus.

Shaun: You got the manual, you need to setup like page 3.2.

(Shaun shows the lab manual to Jared)

Shaun: What we need to do is setting it up like we have the string tied that make contact with this (making some gestures in the air to illustrate), that we have the string on the side like this, mass is hanging on the pulley so that we can hang more masses.

Jared: Ok, let's see.

Shaun: I guess we can use this string (giving Jared a string). So the key is gonna be the right lever.

Jared: What do you mean by right lever?

Shaun: We have to be touching that and it has to go over the pulley.

Jared: How to do that, it's kinda a problem, because the pulley is higher.

Shaun: Yeah.

The episode depicts Jared's interaction with the equipment. Although Shaun was still in charge of Jared's behavior, Jared was given more freedom to explore. In contrast, Abbey was only assigned simple tasks and was excluded from important tasks that could have facilitated her fruitful learning.

Similarly, Jared was given the opportunity to operate the computer and the X-ray box during the X-ray diffraction. Throughout the experiment, Claire took control of the computer at times, but she always returned the space to Jared and let him finish the tasks after the group solved the calibration problem. We did not believe that any member of this group needed to seek permission from their peers before touching the equipment in either

experiment. Rather, they shared with one another in order to learn.

We conclude that the group of Abbey, Will, and Charlie is less equitable than the other group. This is due to Abbey's exclusion from ongoing discussions and important tasks involving experimental equipment. Shaun, Claire, and Jared's group, on the other hand, is more equitable, with all members free to join ongoing discussions and experimental equipment, and all members having equitable opportunities to learn and participate. The fact that Abbey and Jared have the lowest positions in the group suggests that gender does not determine who has the access to learning materials in a group work.

## 2.7 Discussion

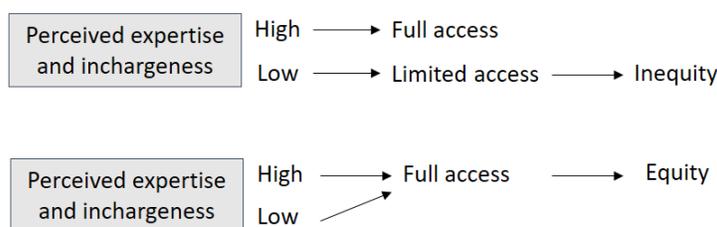
**RQ1: How are perceived expertise and incharge-ness distributed in an advanced physics lab?** This study looks into two constructs to examine social positionings: perceived expertise, characterized by the firmness and confidence in discourses using downward inflection; and incharge-ness, determined by the control over their peers' behaviors and activities. Both positionings are dynamically varied from moment to moment. Thus, positioning distributions are drawn from the most frequently observed trend during the the first 60 minutes of each experiment.

Given two observed social positionings in the group, one can assume four possibilities of the positioning distribution: members with firmness in discourses aren't in charge; members with firmness in discourses are also in charge; members without firmness in discourses are in charge;<sup>60</sup> and members without firmness in discourses aren't in charge. Our analyses reveal similar behaviors of high-incharge-ness members, that is they use the firmness in discourses to direct members with lower incharge-ness than theirs. These are observed when Will and Charlie commanded Abbey in the X-ray diffraction; Shaun commanded Claire and Jared, Claire commanded Jared in the torsional oscillator; Shaun and Claire commanded Jared in the X-ray diffraction. In contrast, Abbey and Jared were consistently directed by peers (lowest incharge-ness) didn't use downward inflections and firm discourses to interact with high-incharge-ness members. From our three case studies, we conclude students with higher

perceived expertise use their firmness and confidence to control their peers' behaviors and direct the group's activities.

**RQ2: To what extent does the distribution of social positionings explain equity?**

An equitable collaboration allows all members to access learning materials (including on-task discussions and experimental equipment) needed for the learning. In contrast, inequitable group work will raise a question of who can and cannot access the learning materials. Fig. 2.8 summarizes the interaction between social positionings and equity.



**Figure 2.8:** *The ways in which equity or inequity can emerge from a physics group work*

Although there is an unequal distribution of social positionings in both groups, the second group (Shaun, Claire, Jared) is more equitable than the first group (Will, Charlie, Abbey). Will and Charlie used their high social positionings to dominate on-task discussions and the equipment. They excluded Abbey in most of their discussions, and the extent to which Abbey could approach the equipment was subject to Charlie's approval. In this case, Abbey, with low perceived expertise and incharge status, has limited access, reducing the equity in this group (the upper part in Fig. 2.8). In contrast, Shaun used his high social positionings to gain access for Jared. Despite his low perceived expertise and incharge status, Jared was granted full access to the on-task discussions and equipment (the lower part in Fig. 2.8). The difference between two groups supports the claim that the unequal distribution of social positionings still can lead the group to equity if members with higher positionings offer members with lower positionings opportunities to engage in the on-task discussion and experimental equipment. Our findings in the context of an advanced physics labs agree with previous studies stating that if one student in a group is clearly in charge of leading the group's activities, the group can still be equitable depending on how the student takes

up the positionings to behave and treat other members.<sup>58;59;61</sup>

On the flip side of our findings, although the low-positioning members can freely join the discussion and equipment, they are still under control of high-positioning students. Previous research shows that introductory physics students, regardless of gender, have similar lab role preferences.<sup>47</sup> If that is the case of the advanced physics lab, we are concerned that low-positioning students have fewer options for what they prefer to perform as high-inchargeness members control who does what in the group.

### 2.7.1 Contribution to equity literature

This study contributes to the existing understanding of equity. First, prior studies suggest that the unequal participation among students is an indicator of inequity.<sup>60;69;70;90</sup> However, our findings suggest that unequal participation among members does not solely represent inequity. Jared, for example, did not speak as much as Shaun. This unequal participation is not indicative of inequity. Instead, the way Shaun used his high social positioning to offer Jared access to the on-task discussion and equipment reveals the group's equitable learning.

Second, instead of focusing on the equality of positioning distribution to infer equity, ones should seek the mutual respect that students should all show to their peers as an underlying key for equity.<sup>58;61</sup> Brookes et al. indicated that the group is less likely to be equitable if group members are consistently positioned as an expert because "it is difficult or impossible to convey mutual respect," in which expert members may rebuff and cut off other members' discourse. Although examining mutual respect can go beyond the scope of this chapter, our findings support this concern that students who consistently have high positionings can take away some learning opportunities of low-positioning students such as Abbey. However, we do see the exception in the Shaun-Claire-Jared group where Shaun with high positionings still shows respect to his peers by not cutting off Jared's opportunity to access the learning materials.

Third, our analysis found no evidence of gender inequity. The similarity in low positionings between Abbey and Jared, as well as Claire's gained positionings in the X-ray diffraction,

and the disparity in the degrees to which Jared and Abbey can access the apparatus, suggest that gender does not account for social positionings or apparatus access in a mixed-gender group. This is in dramatic contrast to previous research in introductory physics lab contexts, which discovered a link between “doing physics” and “doing gender” in labs.<sup>43;46;94;95</sup> Our future work should continue to look into more groups to validate the dissociation between equity and gender in advanced physics labs.

Finally, we looked at Shaun, Claire, and Jared engaging in two different experiments (X-ray diffraction and torsional oscillator), with the X-ray diffraction also being carried out by Charlie, Will, and Abbey to see if the structure of the experiment itself affects equity. While some research suggests that the structure of activities or tasks can aid in equitable collaboration,<sup>57;61;93</sup> regardless of the experiments, Shaun, Claire, and Jared form a more equitable working group than Charlie, Will, and Abbey. This suggests that the nature of these two experiments, such as the location of the experimental setups or the number of devices, may have no effect on equity.

## 2.7.2 Limitations

We highlight some limitations of the study. First, we did not have access to resources such as interviews to ask for students’ perspectives. Our analyses were guided by theory and researchers’ perspectives, but not students’. Holmes et al. reported that when students were asked about their group work experiences, they were generally very positive,<sup>47</sup> which contradicted the inequitable patterns commonly observed by researchers. Furthermore, other factors that cannot be seen in this chapter, such as interpersonal relationships with lab mates or previous laboratory experiences, can influence students’ behaviors.

Second, advanced physics experiments are complex, reflected by the amount of time students spend on each experiment (3 meetings, 3 hours for each meeting). This study only observed one hour during a single meeting. Therefore, our findings can only represent the dynamics of the group during that one hour, and we do not intend to generalize the findings. In addition, our multiple case studies cannot generalize the dynamics as well as

social positionings of all advanced physics labs.

Third, while we argue that the second group is more equitable than the first, our study cannot go into greater detail about whether the second group improves students' learning outcomes. This question necessitates more quantitative data in order to be thoroughly discussed.

### 2.7.3 Implications for teaching

There are some mixed implementations of interventions to navigate an equitable group work. While some studies suggests that labor division is a good way to increase students' agency and collaboration,<sup>96</sup> some studies found that students prefer to work together rather than split.<sup>47</sup> It is noted that labor division in Ref.<sup>96</sup> implies that each student has a control over one specific task, but students brainstorm collaboratively; this concept differs from gender division of roles, which might undermine the group work.<sup>97-99</sup> From our observations of the Shaun-Claire-Jared group, both dividing tasks and sharing tasks can result in equitable interactions. However, whether students should divide or share depends on their progress as a group. Given the complexity of advanced physics experiments, we suggest that it is preferable for the group to be on the same task when they are figuring out the concepts as well as how to operate the apparatus, dividing tasks should only take place when everyone clearly understands the concepts and goals of the experiment. Importantly, even when students divide the tasks, tasks should be opened for peers for join, just like Jared joined Claire's task on plot and Shaun joined both Jared's and Claire's tasks. In short, the division of labor and collaborative brainstorming should go hand-in-hand together to maximize students' learning.

Self-evaluation lists with checkmarks for high/moderate/low positionings, as well as a quick note of how students behave in relation to their positionings (offering or blocking access to peers), can help instructors facilitate equity when grouping students. For example, regardless of gender, low-positionings students who are denied access should be shuffled and paired with high-positioning members who respectfully grant them access. Thus, instructors must implement some classroom policies and practices to encourage students to keep learning

materials opened to everyone.

There will be no perfect solution that ensures equity is established. However, equity can be practiced in order to improve. This chapter proposes some actionable practices that instructors can implement to improve equity: quickly recognizing social positionings in the group, observing how students use their social positionings to treat group mates, intervening if necessary to open access for students with low positionings, and encouraging students to practice both labor divisions and task sharing. Hopefully, combining these takeaways will result in a more equitable learning environment for all students.

## Chapter 3

# Introduction to Purpose and Identity project

This chapter introduces two studies that aim to explore students' sense of belonging and professional life after graduation. In an effort to help improve undergraduate curriculum, the two projects seek influential factors that impact students to explore a sense of purpose and construct their professional careers through a theoretical construct called future possible selves. Throughout the investigation, a cluster of departmental features is identified that can either support or threaten students' sense of belonging. Furthermore, students' motivators for developing future possible selves and sustaining future career goals are discovered. This chapter provides an overview of the context, interview protocol, data collection, data summary, and major research questions concerning sense of belonging and future career development.

### 3.1 Context and data collection

The data was gathered in an urban, private, master's-granting institution in the United States. The University offers a wide range of programs through its ten colleges. The Department of Physics and Astrophysics offers a BS in physics with four concentrations: standard, computational, interdisciplinary, and a joint engineering program with another technology institution, as well as an MS in physics. In 2019, the Department of Physics conducted an internal assessment to better understand physics students' sense of purpose and needs to develop their future career.

The internal assessment of the department went further for research purposes. Prior to the interview time, an email of recruitment was sent to all physics undergraduate students, detailing the purpose of the research project and soliciting their participation.

There were 19 students (7 females, 12 males) participating in the interviews. Two 45 minutes semi-structured interviews were conducted via Zoom. Out of the 19 interviewees, 12 were current students and 7 were alumni. All interviews were taped and transcribed. The interviewers were not associated with the students' university. The overall theme of the project was to investigate the needs and motivations of physics undergraduate students in terms of career planning and sense of purpose, with the goal of improving undergraduate administrations and curricula by identifying what was lacking to meet students' needs. The interview protocol included five major agendas: background; career planning; influencing factors; exploring sense of purpose; and institutional resources. Some examples of interview questions include, but are not limited to: What do you think about your sense of purpose or meaning in life? Who do/did you talk to about things like purpose? How did the institution prepare you for thinking about your sense of purpose? How have physics classes helped you think about purpose or career? The full interview protocol and an example of two interview round transcripts are attached in Appendix A and in Appendix B, respectively.

Six months later, a subset of students was chosen to participate in a follow-up interview. Three researchers who were heavily involved in students' transcripts and had specific reasons to check in with students determined the subset. In the first interview, for example, two

students mentioned being a minority in the physics community and feeling pressured by peers to pursue physics. As a result, the two students were discussed by three researchers and chosen to do a follow-up. Another criterion was that some students had switched domains (for example, from physics to a computer science-related field); we wanted to follow up with students to see how far they had progressed in their career decisions. The second round interview protocol was similar to the first; the most significant difference was the way questions were framed to update students' progress. For example, rather than asking students about their plans for the future, as in the first interview, the follow-up one focused on what they had done and what had changed in the previous six months to prepare for the future professionals.

## 3.2 Data summary

Demographics of participants are summarized in Table 3.1. There were 19 students participating in the first round of interviews. At the time of the first round interview, 7 of the 19 interviewees were alumni; 12 were current students (7 seniors, 2 juniors, and 3 sophomores). Six months later, a follow-up interview was conducted with six students, four of whom had recently graduated. Data collection revealed a large number of double-major students in a variety of disciplines in addition to physics.

As an overview of the data, most students expressed a strong sense of purpose in the connections with their future professional life. However, some students also explicitly expressed that they had never thought much about a sense of purpose. Overall, from students' opinions, a sense of purpose is associated with impacts and contributions to science, universe, society, and humanity. These impacts and contributions can come from either their professional jobs or voluntary work. As students plan for life after graduation, many senior students are choosing graduate schools as the next step in their professional career. Some students are debating back and forth between options such as teaching college vs teaching high school, working in academia vs in industry, and some alumni are considering between going back to grad school vs continuing their current jobs. In terms of institutional and

departmental supports, students have listed a variety of resources that help them to develop a sense of purpose and professional life, such as research opportunities, faculty, conferences, clubs, and scholarships.

**Table 3.1:** *A summary of data collection*

Major and minor	Participant	Year and self-identified demographics
Physics only	Sue (she/her/hers)	Sophomore, WiP
	Holden (he/him/his)	Junior
	Nicole (she/her/hers)	Alumna, Black, WiP
	Jacob (he/him/his)	Junior and transfer student
	Sheila (she/her/hers)	Sophomore, WiP
Physics and Math	Taylor <sup>1</sup> (she/her/hers)	Senior, WiP, also minor in studio art
	Olivia (she/her/hers)	Sophomore, WiP
	Noah (he/him/his)	Alumnus, LGBTQ+
	David <sup>1</sup> (he/him/his)	Senior
	Blake (he/him/his)	Alumnus
	Francisco <sup>1</sup> (he/him/his)	Senior, Latino
Physics and Education	Julia <sup>1</sup> (she/her/hers)	Alumna, LGBTQ+, Jewish
Physics and Math/CS	Ricky <sup>1</sup> (he/him/his)	Senior, also minor in Spanish
	Peter <sup>1</sup> (he/him/his)	Alumnus
Physics, Math, and Philosophy	Molly <sup>1</sup> (she/her/hers)	Alumna, Jewish
Physics and one minor	Math: Carlos (he/him/his)	Senior
	Math: Matias (he/him/his)	Alumnus
	History: Gabriel (he/him/his)	Senior
Joint program: Physics and Engineering	Christian (he/him/his)	Senior (5th year) of the joint program

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<sup>1</sup>Participants were selected for data analyses in chapter 4 and chapter 5.

### 3.3 Research topics

The overarching goal of the broad project was to assist students in building meaningful and purposeful lives. In the context of the larger project, we identified two research topics that emerged from a preliminary data review. First, as previously stated, the data set contained a large number of double-major students. When asked about the institutional and departmental supports that students had received to develop a sense of purpose and a professional life during the interviews, some double-major students shared the differences and similarities between their departments in supporting students to explore a sense of purpose and future career. As a result, we were interested in conducting a research on identifying departmental features that can support or inhibit students' sense of belonging. Second, many of the study's participants were seniors with one or two quarters left to graduate at the time of the first interview. When asked what they intended to do after graduation, some said they had no idea, while others said they had several options. Thus, the second research topic attempted to investigate how students refine their career thinking in order to decide what to do after college. These two research studies are next presented in chapter 4 and chapter 5, respectively.

# Chapter 4

## STEM double-major students perceive a sense of belonging in their departmental communities

This chapter explores double-major students' perceptions of departmental features that can impact their sense of belonging (SB) across four departments: physics, education, math, and computer science (CS). We first take up a Community of Practice (CoP) framework to define that each department is a CoP. Situating the project into the Community of Practice Framework, features of departmental communities of practice are identified that can support or diminish mutual engagement, which is defined as activities that members participate in together to build connections and relationships. Theoretically, the greater the mutual engagement among departmental members, the more likely it is that members will be shifted towards central memberships, resulting in a strong SB in the department. The project conducted semi-structured interviews and multiple case studies to identify a set of departmental features based on participants' perceptions that can impact a SB: collaboration, extracurricular activities, future career supports, and building structure. We conclude that if the four departmental features are perceived to create the mutual engagement between students and faculty as well as among students, students are more likely to develop the central member-

ship in the department, thereby increasing a SB. In contrast, if departmental features are perceived to be less accessible for students to develop mutual engagement, students' central membership is less likely to develop, sequentially lowering students' SB.

## 4.1 Introduction

The purpose of this chapter is to investigate double-major students' perceptions of departmental features that affect their sense of belonging. Sense of belonging (SB), defined as the extent to which students subjectively perceive that they are valued, accepted, and legitimate members of their academic domain,<sup>100</sup> is one of the variables of the learning environment that can have a direct impact on students' learning and identity,<sup>19;101;102</sup> which in turn can predict students' career choices and retention in STEM.<sup>103-106</sup> Early research scholars in the 1990s<sup>16;107;108</sup> all agreed that students' learning will be limited unless they feel valued and accepted in their learning environment.

The correlation between students' learning and SB has been studied extensively up to date. According to research, students with a higher SB are more likely to stay in college and complete their degree.<sup>109</sup> Conversely, students who stay in their majors report a greater SB. Students with higher SB not only have higher academic motivation, engagement, and achievement, but they also feel more competent and have fewer externalizing problems such as stress or anxiety.<sup>110-113</sup> The association between SB and academic outcomes have been tested across many disciplines including math,<sup>114</sup> STEM in general,<sup>105;115;116</sup> physics,<sup>17-19;109</sup> psychology.<sup>111-113;117</sup> Understanding what factors can hinder or bolster SB can be meaningful to instructors and curriculum developers to adjust the learning environment accordingly, leading to better academic outcomes and success for college students.

Findings from previous studies prompt an investigation of why there is a difference in SB among college students. Prior studies have insightfully highlighted factors associated with SB, such as close-knit relationships with parents,<sup>110</sup> peers, and faculty;<sup>118</sup> a threat posed by the environment itself (gender inequality);<sup>119;120</sup> and stereotypes of innate ability and brilliance to do science.<sup>121</sup> However, as detailed in the following section, while the contexts

of SB from previous studies primarily focus on classroom belonging, discipline belonging, and institution belonging, there has been little research on a sense of belonging to the context of departments in which students major.<sup>122</sup> We argue that, while classrooms, departments, and institutions are tightly related, a SB across these three scales is not always the same. An institutional SB might be developed at a larger scope of activities such as cultural exchange, sports, games, international orientations while a departmental SB should be centered more around disciplined-related activities with faculty and peers. This chapter seeks to add to the literature by delving into a more nuanced context of belongingness, namely departmental belonging. We argue that beyond introductory courses where students may come and go after prerequisite courses, juniors or seniors are legitimate members of departments where not only courses but also all department-related activities may have had a significant impact on student SB. Thus, a SB in a department, like a SB in a classroom or an institution, has the potential to play a critical role in students' achievement and retention.<sup>123</sup> With this motivation, we are interested in exploring how double majored students perceive a SB in their departments. To frame the research, the CoP framework is used to theoretically define the context in which the sense of belonging is investigated, namely each department as a community of practice. The framework directs the investigation into how features of the departmental community of practice shape and influence SB.

Following sections will first review different contexts of SB that have been widely focused by the literature and from here highlight the contribution of the current work to the literature. The theory of CoP is next presented and situated in the context of belonging. The analysis presents multiple case studies, indicating the features of each department that might or might not support the development of SB for students. This chapter ends with discussions on the contribution of findings to existing literature on sense of belonging.

## 4.2 Background of sense of belonging

### 4.2.1 Sense of belonging in the contexts of classroom, discipline, institution, and department

A sense of belonging denotes a feeling of relatedness or connection to others in a mutual environment.<sup>124</sup> A classroom and an institution are regarded as important mutual environments in academia where individuals can develop a SB.<sup>100</sup> Thus, measuring SB necessitates a consideration of which context a SB is being investigated, because “sense of belonging in a particular context (e.g., department, classroom) has the greatest influence on outcomes in that area” (p.20).<sup>125</sup> Some scholars investigate SB at various levels - belonging to a class, a discipline, or an institution - in order to investigate the interaction between different levels of SB.<sup>113;126;127</sup>

In the context of the classroom, prior studies found that whether a SB is formed strongly depends on characteristics as well as pedagogy of faculty in class.<sup>110;117;124;127;128</sup> Faculty who are accessible and approachable to students, design authentic instruction, and encourage students to participate, in particular, increase SB for students.<sup>124</sup> Wilson et al. then confirm that there is a strong relationship between classroom belonging and classroom engagement.<sup>113</sup> Besides faculty, peer interactions is another contributor to classroom belonging.<sup>124</sup> For example, being respected and valued by classmates is associated with a high SB in the classroom. In contrast, students with low SB felt uncomfortable and disrespected by their classmates.<sup>117</sup> Altogether, these findings suggest faculty characteristics and good relationships with peers are most important to the development of SB in the classroom.

Beyond the classroom context is discipline belonging.<sup>109;113;114</sup> Although classroom belongings and discipline are related, they are not the same thing. A likert survey statement for classroom belonging corresponds to “I feel like I am a part of this class,” whereas a likert survey statement for discipline belonging corresponds to “I feel like I am a part of this discipline.”<sup>113</sup> To perceive a sense of belonging to a discipline, students may need to be immersed in a field for a longer period of time than just one class.

Another broad context of SB in an academic setting is institutional belonging. Similarly to a classroom context, supportive and good relationships with peers and faculty is a strong contributor to enhancing a sense of institutional belonging.<sup>110;128;129</sup> Furthermore, parental support,<sup>110</sup> as well as participation in campus-related activities such as religious organizations, sororities, fraternities, and sports teams<sup>128</sup> are perceived to contribute to students' SB to the institution.

Among different contexts of belonging, belonging to a department is rarely discussed. Unlike freshmen, who only take classes to fulfill a requirement, juniors and seniors who have declared a major are legitimate members of the departments and spend the majority of their time in their departments taking classes, seeking advice for courses and careers, and even participating in research, seminars, and colloquium. Similarly to the classroom or institutional belonging, we perceive the importance of departmental belonging in students' learning outcome and success. Two of the rare papers have recently explored a SB to the biology department that come closest to our work.<sup>122;123</sup> Findings from the 10 interviews with students who were biology majors revealed that to fully develop a SB in the department, besides a good relationship with peers and faculty, students also need to have a shared professional choice to feel connected.<sup>123</sup>

In physics, a SB also has been examined in various contexts on both undergraduate and graduate students. Undergraduate and graduate students, for example, who facilitate informal physics programs were found to increase their SB to the physics community, resulting in an increase in their physics identity.<sup>130</sup> Other studies with a focus on students' identity and equity in physics use surveys throughout a physics course to identify influential factors on students' SB in physics. Being recognized by instructors or teaching assistants, in particular, is related to a student's SB, which can affect students' physics self-efficacy.<sup>17;19</sup> Ladewig et al., on the other hand, conducted a survey over multiple semesters of a physics course to conclude that women feel a lower SB than men in physics.<sup>18</sup> The study also discovered that a SB predicts the degree to which students see the value of physics in their daily lives as well as their performance on outcomes. Similarly to other fields, physics education has primarily focused SB on a single physics course or a series of physics courses. Thus, while taking into

account previous research findings, we broaden the scope to investigate how students develop a SB in the physics department.

### 4.2.2 Sense of belonging and underrepresented groups

A large body of research is particularly devoted to promoting belongingness among underrepresented students including women, African American, Hispanic Asian Pacific Americans.<sup>112;116;125;131</sup> Women in STEM, for example, have been found to consistently have lower SB than men.<sup>105;115</sup> These findings stay true in physics as a field and in physics classrooms,<sup>17;109</sup> leading to a conclusion that the current environment of STEM-related fields is favoring men. More importantly, the more women report having a strong SB, the more they report an intention to pursue their discipline.<sup>109</sup> In contrast, although men have higher SB than women, their belonging did not predict persistence at all.

Taken all together, research up to date has primarily focused on a SB in three main contexts (classroom, discipline, and institution) with departmental belonging receiving little attention. This work aims to contribute to and expand the SB in the context of the department. Instead of emphasizing what students do to be included or excluded from their departments, we emphasize departmental characteristics, i.e., what the departments have done that may hinder or foster students' SB. This approach is inspired by a model of institutional action,<sup>132</sup> biology departmental actions,<sup>123</sup> and many others,<sup>133;134</sup> with a focus on institutional, departmental, and classroom features that have an impact on students' gains. This current work analyzes double-major students' perceptions to determine which departmental features positively or negatively affect a SB. In addition, we make two significant contributions to the literature of belonging. First, we set aside social identity in order to investigate a SB. We argue that if a community's features and cultures are not designed to support students, all students, regardless of social identity, are at risk of losing their sense of belonging. Second, much SB research has been quantitative in nature, which cannot be explained in depth and may have missed the mechanism underlying the high/low SB.<sup>124</sup> Our work interprets student narratives, deepening the formation of SB that scholars can use for

comparison with quantitative analysis.

### 4.3 Theoretical framework

We employ Communities of Practice framework (CoP) to define the context of this work through which a SB is investigated. Wenger defines a CoP as a group of people who share the same interest in a topic through which they will engage in a learning process to achieve their learning goals.<sup>132;135</sup> A well-functioning CoP needs to fulfill three main characteristics: (i) The domain represents the set of shared interests, passions, and goals identified and negotiated among members; (ii) The community is composed of members who engage in learning activities, build up rapport, develop knowledge and skills together to achieve their shared goals; (iii) The practice refers to a set of tools, norms, languages, ways of talking, etc. that members have developed over time. These practices can be used as unique traits to distinguish the community from others. Using these three characteristics as a theoretical foundation, this study considers each disciplinary department (physics, math, education, and computer science) as a community of practice. For example, the physics departmental community has been established with a shared goal to understand the interplay between matter and energy (the domain). In order to reach this goal, faculty and students form a community where they interact, build relationships and engage in academic activities such as seminars, classes, research meetings, and colloquium to reach the shared goal. Over time, members in the departmental community develop an understanding of different theories and skills of computing and modeling to communicate about science (the practice). Similarly, we consider math, education, and computer science communities of practice with their own shared goal, community, and practices that members develop together.

In addition to identifying a well-functioning community of practice, the framework conceives learning as a trajectory from being peripheral members to central members of the community. The transition from being a peripheral member to a central member requires an engagement in practices and guided by the central members.<sup>136</sup> In the context of the physics department as a community of practice, for example, professors (central members) guide new

students (peripheral members) by teaching students and advising research.<sup>137;138</sup> Over time, the new student shifts towards central membership, indicating the development of identity in the community. In order to measure the memberships and positionality of individuals in the community, Wenger lays down three constructs: accountability to the enterprise, mutual engagement, and negotiated repertoire.<sup>130</sup> We adopt refined definitions from Fracchiolla et al. to interpret what these three constructs mean in the context of disciplinary departments.<sup>130</sup> (i) *Accountability to the enterprise* describes how members understand the goals of the community, and how they perceive their roles as well as responsibilities to reach such goals with other members. (ii) *Mutual engagement* relates to how the community functions and forms of interactions among members, referring to opportunities for shared participation in the activities. (iii) *Negotiated repertoire* is routines, language, methods, concepts, etc. that members develop together while participating in the CoP. In the context of each department as a CoP, taking the physics department as an example, accountability to the enterprise describes how physics students understand the mission and the goal of studying and doing physics. Mutual engagement refers to activities in which students interact with their peers and faculty, such as seminars, classes, research, and colloquiums, and through which relationships and interactions are formed. Negotiated repertoire refers to the skills, norms, methods, language, and routines that physics students develop, such as proficiently using a software to calculate integrals and explaining phenomena using physics theory and equations. Combining these three constructs together informs the positionality of physics students in the department.

In physics education research, CoP has been widely used to study students' identity development.<sup>130;134;138;139</sup> In a study to explore conditions for building a CoP in an advanced physics laboratory, Irving et al. found that structural features of the course and instructional choice of faculty combined together can accelerate the trajectory towards central membership, leading to a development of physicists' identity of students.<sup>134</sup> This study inspires us to investigate the structural features of the department, instead of the classroom, that can support students to move towards central membership of the department. Additionally, prior studies highlight that applying CoP is not as straightforward as being described in theory

because students can be members of several overlapping communities. For example, Irving et al. found that students' memberships are maintained in two overlapping communities: the undergrad physics community of practice and the community of practicing physicists.<sup>138</sup> Fracchiolla et al. analyzed students' memberships in several communities: informal physics program, science research, graduate school, physics, and personal community.<sup>130</sup> Based on the perception of memberships in multiple communities, this study is also intended to explore whether students can develop their central memberships in multiple departmental communities.

In this work, we attempt to explore students' SB in the context of CoP. More specifically, the study investigates the departmental features in four communities of practices (physics, math, education, and computer science) that can impact students' SB. The connection between SB and CoP is supported by the theory itself, stating that the development of the membership is built on alignment of common goals, participation in social interactions, and perception of belonging in the community.<sup>140;141</sup> According to Wenger, shifting toward central membership is associated with the identity development shaped by accountability to the enterprise, mutual engagement, and negotiated repertoire. Previous scholars have connected the CoP framework and SB to conclude that the movement towards the central membership, i.e., developing identity, results in a strong SB<sup>130;141;142</sup> Thus, in this study, we argue that an increase in SB necessarily results from students' movement toward central membership through mutual engagement with other members in the community. The following is our conceptualization of theoretical approach for this study (Fig. 4.3): if mutual engagement (interactions) is established within the department through features facilitated in ways that allow them to reach out to students, students are more likely to move toward central membership, thereby increasing their SB to the departmental community of practice. Here we define features as ways that things work in the department such as how classes are structured, clubs are run, and office hours are typically held. The purpose of this study is to explore students' perceptions of departmental features that can either enhance or reduce students' SB. We ask the following one research question: How do participants' perceptions of departmental features in the physics, education, math, and CS departmental communities

of practice support or diminish their sense of belonging?



**Figure 4.1:** *Theoretical approach to a sense of belonging. If departmental features are perceived to support mutual engagement, it is more likely that students shift toward central membership, sequentially resulting in a increase in SB*

## 4.4 Methods

### 4.4.1 Context and data collection

The context of this study is described in depth in chapter 3. Because interview questions focused heavily on the support students received from faculty, departments, and institutions in exploring their sense of purpose and professional life after graduation, some double-major students shared with us the similarities and differences in culture, relationships, and climate between the two departments in which they majored. As directed by the CoP framework, the analysis focused only on text blocks in transcripts that explicitly discussed the departmental community. The analyses, for example, do not take into account family ties, finances, geography, or personal interests. Out of 19 interviewees, five double-major students were selected (out of 10 double majors) as representatives for the data corpus in this study (Table 4.1). These students stood out to us as they provided robust descriptions about the differences and similarities between departments. When asked about the supports they received to explore a sense of purpose and future careers, these five students specifically mentioned what they received in the X department but not in the Y department, or what they received in both the X and Y departments. The explicit comparisons provided us with rich data to understand how supports are structured in different departments, which may foster or inhibit students' SB. In this study, all students' and professors' names are pseudonyms and masked.

**Table 4.1:** *Data corpus*

Names	Year	Major 1	Major 2
David (he/him)	Senior	Physics	Math
Julia (she/her)	Alumna	Physics	Education
Taylor (she/her)	Senior	Physics	Math
Ricky (he/him)	Senior	Physics	Math and CS
Peter (he/his)	Alumnus	Physics	Math and CS

#### 4.4.2 Data analysis

To achieve an in-depth understanding of the development of SB, multiple case studies methodology<sup>143;144</sup> and a constant comparative method<sup>145</sup> for the analysis were both conducted. It is noted that as a qualitative research method, the goal of case study is not to produce generalizable conclusions across all institutions, but rather provides a rich understanding and nuanced patterns of a phenomenon.<sup>146;147</sup> Furthermore, because qualitative research interprets people’s lived experiences in order to investigate a phenomenon, this study attempts to interpret students’ perceptions of departmental features rather than determining the objective truth of each department to judge. We also recognize that, while we believe that students’ perceptions are accurate, i.e., that students’ feelings toward their departments are authentic and honest, human perceptions are limited and individualized, and cannot be used to generalize the culture of the entire department. Thus, the ultimate goal of our analyses is not to determine how effective or ineffective each department is, but rather to identify ways that departmental features can be facilitated to support students’ SB.

The analysis started by reading through the selected blocks of text that focused on department descriptions, such as activities that faculty and students do together, how classes/research groups are run, types of interactions that students have with other students or faculty outside of the classroom, and so on. To begin interpreting the text, we relied on three CoP framework constructs. The two constructs - accountability to the enter-

prise and negotiated repertoire - were not mentioned frequently in students' narratives, as we discovered. It was reasonable because the interview was designed to assess neither how well students understand the department's goals and mission (accountability to the enterprise) nor how competent students are in physics equations, laws, and programming (negotiated repertoire). Therefore, the analyses focused on mutual engagement.

We assembled quotes that were marked as mutual engagement. To be identified as a mutual engagement, a quote must include an activity or interaction in which students and faculty both participate. The activity or interaction may result in the formation of a relationship between students and faculty or among students. A quote like "It was people talking about math really openly and open to anyone coming up and talking to them" is an example of mutual engagement because it includes people talking (interacting) about math. In other words, people converse about math with one another. A quote that is not marked as mutual engagement is "So I've considered working in more of a statistical mechanics because that's extremely interesting and something I enjoy" because this quote is a personal interest of a student and does not involve the interactions with other members. While identifying mutual engagement, we paid attention to which department the student was referring to. After collectively classifying mutual engagement quotes in each students' transcript, we grouped all mutual engagement quotes on (i) the physics department across five students, (ii) the education department across one student (Julia), (iii) the math department across four students (Peter, Ricky, David, Taylor), (iv) the CS department across two students (Peter, Ricky). The grouping resulted in four groups of mutual engagement quotes (physics, math, education, and CS).

Multiple case studies, as a methodology, not only target information-rich sources for in-depth understanding, but also generate cross-case comparison by using constant comparison methods to determine similarities and differences among case studies.<sup>147</sup> In constant comparison, data are grouped together on a similar dimension. One dimension is given a single name; it then becomes a theme (in our case, it becomes a departmental feature).<sup>144;147</sup> This method was used to examine four groups of mutual engagement quotes. As a result, a comparison between departments emerged on a variety of dimensions. The constant compar-

ative method was applied in two significant places. The first place was to compare student quotes within each group to see how students perceived mutual engagement within a single department. We collected quotes that alluded to the same meaning (for example, lectures, exams, professors, peers, and research) and let the themes (in this case, departmental features) emerge. The cross-case comparison came in second place, comparing the similarities and differences in features across four departments. Following the constant comparative method, we did not hierarchize which student or group to examine first. We simultaneously and iteratively examined quotes of five students and four groups of mutual engagement quotes to develop categories that could represent both features of each department and the commonalities/differences among departments.

## 4.5 Findings

Four case studies are presented in this section: physics, education, computer science, and math departmental communities. We highlight how each feature in each case study is structured based on students' perceptions that can support or diminish mutual engagement, thereby supporting or diminishing students' SB. A set of four departmental features (corresponding four themes emerged from the analyses) is perceived by students that can impact their SB: collaboration, extracurricular activities, future career support, and building structure (Table 4.2). In general, we found that if these features are perceived to be accessible to students, mutual engagement between faculty and students, as well as among students, increases, thereby supporting an SB. In contrast, if students feel that they don't have an access to collaboration, extracurricular activities, future career support and building structure, their mutual engagement in the department decreases, thereby reducing their SB. As a result of multiple case studies methodology with the constant comparison method, a cross-case comparison (Table 4.2) emerges to compare and contrast students' perceptions of the four departments on four dimensions: collaboration, extracurricular activities, future career support, and building structure.

**Table 4.2:** *Cross-case comparison of students' perceptions of departmental features*

<b>Departmental features identified from students' perceptions</b>	<b>Students' perceptions of the Physics department</b>	<b>Students' perceptions of the Math department</b>	<b>Students' perceptions of the Education department</b>	<b>Students' perceptions of the CS department</b>
<b>Collaboration</b>	Students feel that courses are designed to support collaboration	Students feel that courses are designed to support collaboration	Students feel that courses are not designed to support collaboration	Students feel that courses are not designed to support collaboration.
<b>Extracurricular activities</b>	<ul style="list-style-type: none"> <li>• Students feel that they are encouraged and funded to participate in extracurricular activities</li> <li>• Students find research opportunities accessible</li> </ul>	Inconclusive (Students find research opportunities either accessible or inaccessible)	N/A	N/A
<b>Future career support</b>	Students feel that faculty support the career development	Students feel that faculty support the career development	Students feel that there is less support in career development	N/A
<b>Building structure</b>	Inconclusive (Students feel that the building may either support or diminish interactions)	Students feel that the building structure supports the interactions	N/A	Students feel that the building structure reduces the interactions

#### 4.5.1 The physics departmental community of practice

The majority of participants feel that collaboration, extracurricular activities, and future career support in the physics department reach out to them, increasing mutual engagement between them and faculty as well as between them and peers, and thus fostering their SB. Students perceive the last feature, building structure, differently. While some students feel that the physics building reduces interactions, others perceive that it facilitates the formation of relationships with others in the department. In this section, we discuss how students perceive four departmental features in the physics community.

## Students' perceptions of collaboration in physics courses

Lectures in the physics classroom are designed to encourage collaboration. Professors' pedagogical choices encourage students to work in groups, fostering mutual engagement among students to interact and form relationships: "In the physics department, we really don't have lectures, maybe you'll get like 15 minutes lectures in the beginning" (Taylor), after that students are "put into collaboration." Agreeing with Taylor, Julia values the pedagogy of group work: "I think a lot of the professors did a great job at, you know, kind of initiating group work so we would all be struggling together" (Julia). Not only initiating the group work, physics professors also advise students how to have a productive collaboration as Peter recalls: "I remember Professor M doing different kind of stand-up experiments like showing us how things work, and we got to play around, which was always fun, [Professor M] forcing students to not always stay in the same group...forcing people to meet other people would be somewhat good" (Peter). These pedagogical choices, i.e., short lectures, stand-up experiments, and collaboration, inside the physics classrooms are mutual engagement that connect students together. A strong mutual engagement inside the classroom can support a SB inside the classroom.

Outside of the classroom, physics students are even more collaborative working on assignments together. Julia said: "The amount of group work in class and outside of class, I mean, we were all in the labs working through almost every assignment together and just kind of learning together the whole time" (Julia). Perceiving similarly to Julia, Taylor remembers that "homework is hard. I'd be sitting up with my friends like so late in the math or physics department trying to get it to work on the chalkboard" (Taylor). Even during a pandemic where the accessibility to the physical department is limited, Taylor and friends maintain group work: "I definitely do a lot of studying, even online I'll always throw up a zoom with my friends before exams and stuff. Like with the transition right now, just like going on zoom and sharing a doc and trying to figure out what's going on with our problem sets" (Taylor). The collaboration promoted by physics professors, therefore, creates the mutual engagement even outside of the classroom, indicating a SB to the department as Julia stated:

“We saw teachers as friends and classmates, we were always helping one another...Like, we could all work together in some way, shape, or form without any problem and that could be in class or outside of class, but I think it really helped that the professors pushed us to work in groups and established different relationships through our lab groups” (Julia).

Altogether, students feel that physics courses are designed to support the collaboration both inside and outside the classroom. The collaboration initiated by physics professors creates more mutual engagement for students to form the connections and relationships with peers. In line with our theoretical approach (Fig. 4.3), the strong mutual engagement can help students develop central membership, thereby increasing a SB in the physics community.

### **Students’ perceptions of extracurricular activities**

Students perceive that the physics departmental community organizes a variety of extracurricular activities and encourages students to participate. Mutually engaging in these activities provides students a chance to form relationships with faculty and experts in physics that can move students towards the central membership of the department.

For example, “the physics department every single year they have this thing called research day where all the professors just give like a two to five minute like talk on what their research is and like what type of students they’re looking for” (Taylor). To ensure that students can get the research opportunities, “the physics department really pushes people to get involved” (Taylor). This feature of the department helped Taylor and David to communicate with faculty about research, and to be recruited to a research team. “So I went to that and I thought Dr. P’s research looked ridiculously cool, but I was a freshman and he’s the head of the physics department so I was nervous to go talk to him, I went up and talked to him and he’s like, yeah, I’ll work with you, but you need to learn how to program” (Taylor). Similarly to Taylor, David expresses his appreciation for research where he found out his interest in education research and he finally got into the research team with a physics professor: “I talked to Dr. M because I enjoyed the type of research they were doing and then now I do that research and I think, yeah, I think that’s part of why I stayed in the field

in physics” (David).

Besides research day, “the big big thing that [the institution] has done is send [students] to conferences” (Julia) and “it is nice that the physics department likes to fund people to go to conferences” (David). Sending students to conferences is another prominent feature of the physics department that can mutually engage students with the field and build relationships with experts, which in turn can help students not only develop a central membership to the department but also potentially give students a sense of being a member to the physics as a field. Peter recalls that: “I went to the APS March meeting, a large conference where you present a poster. So I was able to present a poster, which was an introduction to the more academic research-y side of the world, which was an interesting opportunity. Kind of visiting different talks, seeing how people present research and get exposure to research” (Peter). Agreeing with Julia, David and Peter, Ricky perceived that “I think something that I haven’t seen at other schools that I think physics does really well is promoting and pushing students to go to conferences. I went to a lot of science conferences, and so from those conferences, listening to, seeing other students’ research, just having like colloquium speakers, seeing what their career paths are and what they are currently doing” (Ricky).

Additionally, the physics department “[is] pretty good about getting word out” to keep students updated about upcoming events, “like, [students are] always getting emails about things like different REU’s and stuff like that” (Taylor). Besides, the department “sends useful things like look at this career program, look at this program for the upcoming years. There might be a useful little flyer about conferences, applying to grad schools and writing effective CVs and resumes, REU advice things, interview advice things” (David). Maintaining communication and keeping students updated with news can make students feel connected to the department.

In summary, extracurricular activities in the physics department are designed in ways that they all reach out to students. Students, in return, feel that they are encouraged by the department to attend, fostering the mutual engagement with peers and faculty. Thereby, a SB in the physics department is more likely to develop.

### **Students' perceptions of future career support**

Besides courses and extracurricular activities, students feel that they receive future support from physics faculty. For example, physics professors are willing to have “extensive meetings” with students to talk about letters for jobs as Taylor said “I’ve had extensive meetings with all of my. . . the people writing the letters are Dr. P, who did my first research, [Dr. F, who’s my math research], and Dr. S, who I’ve just had for like six physics classes and have TA’d for, so it was just like an obvious choice” (Taylor). Feeling the same way as Taylor, David said: “I’ve been talking with Dr. M about worries about the future and about my career path, which is connected to my purpose. I also have been talking with our department chair. He’s been supportive and helpful with thinking about careers” (David). Similarly to David, Julia “mainly talked to physics professors about [careers]. [She] talked to Dr. M a lot about what [she] wanted to do.” The support from physics faculty to future careers makes students feel that they have an access to forming a relationship with faculty (mutual engagement), which in turns can increase students’ SB.

### **Students' perceptions of the physics building structure**

The feature of building structure is perceived differently by students. Taylor feels that the physics building reduces chances to form connections with other students, this is contrasting with the math department building where she can easily form the conversations with math members: “The physics department, it’s like, you know, the grad students have their own room, they stay there, undergrads have their own room, professors are on the other floor. Like, you can always go up to the professors, but it’s that extra step whereas in the math department, I’ll just be working on a board and my professor will just walk by me and be like, “oh, hey, whatcha doing?” (Taylor).

In contrast, Ricky perceives that the building structure of the physics department (and math) allows the interactions among students to occur easily: “I’d say that math and physics department were really similar in the fact that you could just go into the department, there would be people hanging out in the hallways or in a tutor room doing homework or just

talking in the hallways together. I really liked that, that's kind of like that family aspect of a department, or just kind of like there's a central location, all things math departments are there, all things physics departments are happening over there. So that was really nice, and I enjoy that experience because it allows for collaboration to happen really easily" (Ricky). In contrast to what Taylor perceives, Ricky does not consider the building structure to be a barrier to interacting with physics members. Based on Ricky and Taylor's differing perceptions on the physical setup, we cannot conclusively determine whether the building structure is a feature that enhances or detracts from mutual engagement.

To summarize, collaboration, extracurricular activities, and future career support as features of the physics department are facilitated in a way that can reach out to students. Students, in return, have an access to enhance the mutual engagement with peers and faculty. In the line with our theoretical approach, the strong mutual engagement can sequentially support the central membership in the physics community, thereby fostering a SB. One feature, building structure, is not consistently perceived by Taylor and Ricky. To strengthen our theoretical approach that the formation of mutual engagement in the community can ultimately support a SB, we collect some statements from students that implicitly or explicitly stated that they feel belong to the department. Since a SB is defined as feeling related or connected to others, statements below from students indicate a strong connectedness among physics people. Thus, they evidently cue a strong SB to the physics departmental community. We conclude that features of physics department are designed to reach out to students, increasing the mutual engagement and, in turn, supporting students' central membership development, resulting students' strong SB in the physics department.

David: "I think it's more of a community. We all know what everybody is doing. I can list what every faculty member is doing. What every grad student is doing, there is interconnectedness to knowing what everybody is interested in and what they are planning to do."

Julia: "I just really enjoyed the community. I never really encountered a lot of those types of identity barriers. No one tried to inhibit my abilities or my path. So it was a really good community."

Peter: “Physics department is like a home. We kind of get to know all the different professors because there’s not a lot and you kind of become friends with your professors.”

Ricky: “I’d say the math and physics department were really similar in the fact that you could just go into the department, there would be people hanging out like in the hallways. I really liked that, that’s kind of like that family aspect of a department.”

## **4.5.2 The education departmental community of practice**

Julia is the only person that double majors in both physics and education in the data corpus. Interestingly, Julia seems to have contrasting SB in the two departments. While in the physics department, Julia “enjoyed the community,” and thought “a lot of students, at least in the physics program, were very welcoming” (Julia). A SB in the physics department is proved by the relatedness that she feels: “They knew me by name, you know, we knew each other by name. I knew most of my classmates every year” (Julia). In contrast, when Julia talks about her education professors, she said: “I definitely didn’t have as great of a relationship with them as I did with my physics professors. I don’t really know why, actually, looking back at that. I didn’t feel compelled to really talk to them about stuff” (Julia). This quote signals a less mutual engagement between Julia and faculty, which in turns may reduce her SB in the education department. In order to better understand the difference in SB, we highlight Julia’s perceptions of education departmental features that may diminish her SB. It is noted that students’ perceptions are limited (as emphasized in Sec. 4.4.2), Julia’s perceptions of the education department are individualized and legitimate only to Julia, and they do not represent the ultimate truth of the education department as a whole.

### **Julia’s perceptions of collaboration in education courses**

Julia does not feel that education assignments require students to work in groups, although “a lot of the group work was in class for a couple of minutes, outside of class there wasn’t really any group work to do” (Julia). This can diminish a mutual engagement that students could have gotten to build connection and relatedness outside of the classroom. This is in contrast

to the physics department where “in physics, you would rely on your lab group to develop answers or talk about what went wrong or how could we fix this” (Julia). Alternatively explaining the lack of collaboration in the education department, Julia perceives that “[she’s] had a natural inclination towards education and being a teacher so those classes weren’t necessarily difficult” (Julia). From Julia’s perspectives, besides physics professors pushing students to collaborate, it seems that physics problems seem to be more difficult which can be a factor why physics students more mutually collaborate, leading to “a lot more communication and focus on your classmates and relationship in physics than I think in the education program” (Julia). We conclude that Julia’s perceptions of a less collaboration both inside and outside the education class can reduce her mutual engagement with peers. In the line with our theoretical approach in Fig. 4.3, the reduced mutual engagement may diminish Julia’s SB in the education department.

### **Julia’s perceptions of future career support**

When being asked about her future career plans as well as support Julia has received from her departments, Julia “mainly talked to my physics professors. Like [she] talked to Dr. M (in physics) a lot about what [she] wanted to do” (Julia). In contrast, Julia’s academic advisor in education “was not helpful, so [she] didn’t really talk to [her advisor] much, aside from choosing classes” (Julia). We cannot generalize from Julia’s perceptions that faculty from the education department do not support students in their future careers. Julia, on the other hand, may feel as if she lacks access to form communications with her education advisor. Not talking to faculty can clearly reduce Julia’s mutual engagement with faculty, lowering her SB in the education department.

### **4.5.3 The computer science (CS) departmental community of practice**

Ricky and Peter, in addition to physics, have a second major in mathematics and computer science, which is a joint program between the math and computer science (CS) departments.

Despite the fact that the program is joint by both departments, Ricky and Peter discuss them separately. As a result, we treat the CS department separately from the math department, which is covered in the following section. In general, Ricky and Peter do not feel connected to the CS department. The perceptions of less collaboration and less connections due to the CS building structure diminish mutual engagement between students and faculty as well as among students in the CS department, sequentially lowering Ricky's and Peter's SB. We acknowledge that Peter's and Ricky's perceptions, like Julia's in the education department, are only valid to them and cannot be generalized as objective truths about the CS. Our goal is to show how CS departmental features can be redesigned to connect with students, thereby creating more mutual engagement for students and fostering students' SB.

### **Students' perceptions of collaboration in CS courses**

“Another component within the CS department was a lot of the courses you could take, online, remotely” (Peter). Peter perceives that the nature of online courses significantly inhibits students to mutually engage in discussion or group work: “You're sitting in a classroom with like 30 people, but there's like another 30 or 60 people that you never get the opportunity to fully interact with and learn with” (Peter). This is in contrast to the physics department where Peter feels that students have an easier way to interact with peers: “It was always in person you got to interact with your fellow classmates. It was always good” (Peter).

While online classes can reduce students' interactions, office hours not as accessible as in the physics department is another departmental feature in CS that can diminish the mutual engagement between students and faculty. According to Peter, “the physics professors have open doors, you can walk in and see who's there and whatnot. Within the CS everything's kind of behind, you know, locked doors. You can't really just go in and see a professor, you have to always make kind of an appointment ahead of time, you can't really just drop in” (Peter). From this, we argue that the difference in office hour policy between the physics and CS (open door vs locked door) can contribute to a students' feeling of being more related to

physics professors than CS professors, leading to a stronger SB to the physics department than the CS department.

We conclude that Peter's perceptions of less collaboration in courses as well as limited office hours can reduce his mutual engagement with peers and faculty. In line with our theoretical approach (Fig. 4.3), the reduced mutual engagement can lower the likelihood to develop central membership in the CS department, sequentially lowering Peter's SB.

### **Students' perceptions of the CS building structure**

"The CS department, it's kind of a way bigger department so it's kind of difficult to get personal relationships within CS" (Peter). Agreeing with Peter, Ricky found it difficult to build relationships with his CS cohort. While Ricky "liked the family aspect" of the math and physics departments, "then for the other one of computer science, that wasn't really the case" (Ricky). Explaining his own feelings, Ricky reports that the location of the CS department and building structure decrease the chances of building relationships: "[The institution] has two campuses, the computer science department is in the [downtown campus], and then math and physics are on the other campus, the divide was there physically in distance" (Ricky). Not only is the CS located in another campus that makes it more difficult to interact with people, "there isn't really a singular floor or two floors of a building in the CS department. It is more dispersed, there's five or six buildings, so offices spread out between all of these buildings, so it's a lot more disjoint" (Ricky). The "disjoint" structure of the department reduces the mutual engagement to build relationships: "My experience of getting involved in that department or making friends with the professors or having a continued relationship with the same professor over a number of years didn't really happen" (Ricky). Ricky's perceptions of not having a "continued relationship" with his professor indicate little mutual engagement between Ricky and faculty. According to our theoretical approach, a lack of mutual engagement can pull Ricky away from the central membership, reducing his SB in the CS department. While mentioning "a family aspect" in the math and physics department, in the CS department, Ricky said that: "You come here, you have

a class, do the homework, and you go to office hours and stuff too, but there was never that like family feeling” (Ricky).

To summarize, from Peter’s and Ricky’s perceptions of the CS department, collaboration and CS building structure are not facilitated in ways that can reach out to Peter and Ricky personally. As a result, Ricky and Peter do not feel they have access to engage in mutual engagement with peers and faculty, reducing the likelihood of developing a central membership and, ultimately, a SB, as evidenced by Ricky’s quote, “there was never like family feeling.” When asked if the building structure is one of the reasons why the family aspect is not established in the CS, Ricky states that “physics was [his] primary major,” and that he was “clearly a physics person first, and then computer science second,” indicating a stronger central membership in physics than in CS. Ricky’s statement supports our theoretical approach that central membership in a community is associated with a strong SB in that community.

#### **4.5.4 The math departmental community of practice**

The math community, among departmental communities, provides an interesting case study in which students have diverse and opposing perceptions of departmental features. While Taylor and Ricky can find mutual engagement with peers and faculty, David has a more difficult time forming interactions in the department. We present some departmental features as well as student narratives in order to understand the mechanism underlying such contrasting feelings toward the math departmental community.

##### **Students’ perceptions of collaboration in math courses**

When being asked about the difference between physics and math, Taylor reports a similar course structure between physics and math in which both are designed to support collaboration. For example, “the math department is equivalent to the flipped classroom thing that physics does. Instead of this is how to write the proof, we had to figure it out and [the instructor] would pick someone to go to the front and try to present” (Taylor). This flipped

structure of math class promotes students to work together: “That was where the importance of productive struggle and collaboration hit home in the math department” (Taylor). Outside of the classroom, the collaboration continued as Taylor said before: “I’ve had a lot of late night chalkboard sessions in the physics and math departments with my friends” (Taylor).

Taylor’s perceptions indicate collaboration promoted both inside and outside math courses, creating mutual engagement among students. In line with our theoretical approach, the increased mutual engagement through collaboration can support the central membership, sequentially fostering students’ SB in the math department.

### **Students’ perceptions of extracurricular activities**

In the math department, math club is where Taylor found out her opportunity to get into research and helped Taylor to develop the relationship with math professors. Taylor recalls: “We have a math club. We meet once a week and usually a professor or a student gives an hour-long undergraduate accessible presentation on just something math related” (Taylor). In one of the presentations, Taylor found out that she wanted to get involved in doing fractals research: “This particular week, this professor, Dr. F, was talking about fractals and the whole presentation I was like, “this is just so cool”. At the end, she’s like, yeah, I’m looking for students, and so I just ran up to her and was able to start my research” (Taylor). Taylor’s perceptions indicate that extracurricular activities, in this case math club and research opportunities, are accessible to Taylor, increasing the mutual engagement between Taylor and peers/faculty.

As opposed to Taylor who “didn’t have to go knock on people’s doors or anything to get research,” David did not find such an opportunity to do research. To David, while “in the physics department, we have research day and people generally talk about their research, which is awesome, in the math department that doesn’t really happen” (David). Although the math department “have weekly meetings where they talk about people’ research, which is nice, but there is less of a gateway into getting into the research” (David). From David’s

perceptions, research opportunities are not accessible in the math department as in the physics department. To put it another way, research opportunities in the math department do not personally reach out to David, reducing his mutual engagement with peers and faculty and, as a result, lowering his SB in the math department.

### **Students' perceptions of future career support**

Among math students, only Taylor mentions the support of math faculty for her future careers. It is noted that Taylor acknowledges the future career support from both her physics and math professors: "I've had extensive meetings with all of my... the people writing the letters are Dr. P, who did my first research, Dr. F, who's my math research" (Taylor). We conclude that the Taylor's access to faculty increases her mutual engagement, in turns fostering her SB in the department.

### **Students' perceptions of the math building structure**

Taylor perceives that the building structure of the math department makes it easy to mutually engage in discussions with people: "I think it's partially just how the math department is physically set up, it's a huge circle and it's lined with chalkboards and in the middle is like the math tutor room. Every time you walk into math, I mean not now, but during normal times, you'd walk into the math department there'd be some grad students huddled around this chalkboard, and like there'd be teachers on this one. It was people talking about math really openly and open to anyone coming up and talking to them" (Taylor). The quote from Taylor demonstrates interactions that Taylor has with her peers (mutual engagement) and also demonstrates Taylor's sense of connectedness (SB) in her department.

Ricky agrees with Taylor on the building structure that increases the mutual engagement in the math department: "I'd say that math and physics department were really similar in the fact that you could just go into the department, there would be people hanging out in the hallways or in a tutor room doing homework or just talking in the hallways together" (Ricky). However, differing from Taylor's perceptions of the building structure of the physics

department, Ricky perceives that the building structures in both departments (physics and math) allow the interactions to happen easily.

In conclusion, students seem to have contrasting perceptions regarding the accessibility to math departmental features, causing a difference in mutual engagement among students. While Ricky “liked the family aspect” in the math department and Taylor had an easy time finding research opportunities, David did not find a gateway to get into research. The disparity in students’ perceptions suggests that research opportunities, whether through math clubs or weekly meetings, should be restructured in a way that allows all students to develop mutual engagement with research faculty. Otherwise, a lack of mutual engagement can hinder the growth of central membership, lowering students’ SB in the math department.

## 4.6 Limitation of the findings

While conducting a cross-case comparison can provide a comprehensive picture of commonalities and differences in students’ perceptions of features between departments, our analyses have some limitations. The most noticeable limitation is the disparity in the distribution of opinions within each department. For example, in the physics department, we obtain a rich description of features in part because all students major in physics. Thus, combining the narratives of five students may result in more positive features for the physics department than if we only heard from one student. Placing the features of the physics department (obtained from 5 students) next to the features of the education department (obtained from only 1 student), for example, may not be the best way to compare. Thus, we do not attempt to generalize our findings and impose opinions from one student or a group of students on the entire department as a community.

Next, the original goal of this study was to improve the climate in the physics department, so the initial recruitment was aimed at physics students. Students who responded to the recruitment may have a favorable attitude toward the physics department. We had no control over students’ personal feelings toward one or more departments as researchers. We can only do our best to interpret students’ perceptions in order to better understand how to structure

departmental activities that can enhance or inhibit students' SB.

Finally, as acknowledged in Sec. 4.4.2, students' perceptions are accurate but limited. We believe that students reported their true feelings, but their feelings were valid only to them and should not be generalized as the objective truth about the departments. As a result, we make no claim that the physics department is better than others at making physics students feel welcome. Students' feelings differ across departments, either because departmental activities are not yet structured in ways that allow them to reach out to students effectively, or because students prioritize developing central membership in one department over another. Based on the scope of our research, we cannot say which is correct.

## 4.7 Discussion

In this chapter, we take up the Community of Practice (CoP) framework to first consider each department (physics, math, computer science, and education) as a community of practice. Within each CoP, we explore double-major students' perceptions of departmental features that can either support or inhibit their sense of belonging (SB). Supported by theory<sup>132</sup> and prior scholars,<sup>130;141;142</sup> our theoretical approach is that if mutual engagement (interactions) is established within the department through features facilitated in ways that allow them to reach out to students, students are more likely to move toward central membership, thereby increasing their SB to the departmental community of practice.

Conducting multiple case studies and constant comparison method reveals students' perceptions of four departmental features that influence their SB: collaboration, extracurricular activities, future career support, and building structure. Table 4.3 describes the conditions under which these features can foster students' SB, as well as some takeaways for instructors on each feature. We conclude that if these features are intentionally promoted and structured in ways that can reach out to students, that is, if students feel they have access to these features, there will be an increase in mutual engagement between students and faculty as well as among students, thereby supporting a central membership and, as a result, enhancing

**Table 4.3:** *Ways of promoting departmental features to enhance students' SB*

<b>Departmental features</b>	<b>Descriptions</b>	<b>Implications for instructional design</b>
<b>Collaboration</b>	Students feel that they have opportunities to collaborate with peers both inside and outside the classrooms	Promoting group work with an intentional inclusivity
<b>Extracurricular activities</b>	<ul style="list-style-type: none"> <li>• Students feel that they are encouraged and funded to participate in extracurricular activities</li> <li>• Students find research opportunities accessible</li> </ul>	<ul style="list-style-type: none"> <li>• Having some policies to fund conferences and widely disseminating the accessibility of funds</li> <li>• Incorporating research into undergraduate program and checking for accessibility both local and external</li> </ul>
<b>Future career support</b>	Students feel that faculty are available for career-related conversations	Offering explicit conversations with students about future careers
<b>Building structure</b>	Students feel that they can form interactions with peers and faculty inside the departmental building	Promoting collaboration stations for students to work in group inside the department

an SB. In contrast, if these features, for some reasons, do not successfully reach out students (e.g., some students cannot find research opportunities), mutual engagement will decrease, sequentially lowering students' SB.

Overall, our findings are aligned with prior study on biology department belonging, highlighting the faculty and peers is the most common way for students to perceive their departmental belonging.<sup>123</sup> Despite the fact that our goal was to investigate departmental SB as a separate context from classroom, major, or institution contexts, the findings show that there are many overlaps, implying a strong association between the contexts to increase students' SB overall. For example, the feature of encouraging collaborations and peer interactions contributes to students' SB to the physics department. This finding is consistent with classroom belonging, emphasizing the significance of peer interactions, faculty characteristics, and productive pedagogy in developing classroom SB.<sup>110;117;124;148–150</sup> Additionally, we agree with Irving et al. that the instructions and pedagogical choices of instructors set the conditions for the formation of a CoP not only inside physics labs but perhaps in all types of classrooms.<sup>134</sup>

In addition to the overlap between departmental and classroom belonging, we obtain some nuanced features to construct SB for the department that extends beyond the classrooms. Participation in extracurricular activities outside of the classroom, for example, is an important component in increasing the department's central membership. Students value scientific events, research opportunities, and conferences because they allow them to not only expand their social network with peers, faculty, and even experts outside of the department, but also to increase their disciplinary knowledge through research and professional ideas through conferences. This feature is aligned with findings of Knekta et al. showing that the involvement of field trips, journal clubs, or workshops is necessary to promote a SB in the department.<sup>123</sup>

Among the department's features, the building structure is the most surprising, as we did not expect the physical structure to have an impact on students' perspectives. Surprisingly, our findings are consistent with the perspectives of biology students, namely that the size of the classroom and the dispersed structures of departments can prevent students from interacting with and building relationships with other members of the departmental community.<sup>123</sup> Although this feature is important because it is the result of student input, we believe that the department's building structure is the most difficult to adjust. Alternatively, the department can promote some collaboration stations for students to work in group inside the department.

In conclusion, the holistic cross-case comparison among departments based on double-major students' perceptions identified four primary features that can impact students' SB: collaboration, extracurricular activities, future career support, and building structure. According to our findings, students regard collaborations and peer interactions as an important component of their SB, implying that faculty should provide students with more opportunities to collaborate with peers, such as group projects and group assignments. Furthermore, relationships with faculty, faculty support in professional development, and departmental encouragement for extracurricular activities can all have a direct impact on students' SB. For a CoP to be successful, faculty and staff in each department must coordinate together to ensure that students' needs to develop the central membership are heard and addressed

by the departments that they are affiliated with.

## Chapter 5

# Undergraduate students develop and envision future possible selves after graduation

The last overarching component examined in this dissertation is future career. This chapter is situated within the Possible Selves Theory to explore senior students and recent alumni in STEM envisioning future professional identity. Longitudinal semi-structured interviews at a large urban university in the United States were conducted to ask participants about their career plans and resources they needed to develop future possible selves. This chapter presents multiple case studies of physics students exploring, adjusting, and refining their future possible selves. Overall, all case studies express well-elaborated future possible selves constructed by integrating academic and sociocultural experiences. In particular, positive academic experiences from courses, research, and conferences enhance students' interest and self-efficacy in a discipline/field, resulting in constructing future possible selves in the field. However, consistent with prior study, negative experiences such as not being valued by peers can reduce students' self-efficacy, sequentially sabotaging students' possible selves in the field. Personality, living habits, and social identity are also incorporated in order to make future selves congruent with sociocultural experiences. Additionally, we also observe two

possible selves trajectories taken by participants: a narrowing path in which students first develop initial future possible selves in a career area and then develop more specialized selves in that career area, and a sequenced path in which different future possible selves in different career areas are explored in series until students figure out what works best. Implications from findings are discussed to better support students' professional development.

## 5.1 Introduction

As scientists and engineers are the backbone of economy's development and innovation, the call for increasing the retention in college and maintaining the science, technology, engineering and mathematics (STEM) capacity has been continuously emphasized over the last decades.<sup>151</sup> The National Science Foundation (NSF) estimates that the STEM workforce will account for nearly a quarter of the total workforce in the United States.<sup>152</sup> In addition, STEM expertise is required not only for STEM-related careers, but also for many other occupations that are increasingly requiring STEM skills to adapt to new processes and technology.<sup>152</sup> Thus, there is a need for involving students in STEM fields while also assisting them in developing professional identities as college students.

Across STEM education and workforce, women and minorities (Blacks or African Americans, Hispanics or Latinos, and American Indians or Alaska Natives) have remained underrepresented in STEM.<sup>152;153</sup> Among STEM fields, physics has been known to be the least welcoming and diverse to women and minorities.<sup>13;15;154;155</sup> A national data research conducted in 2016 showed that women's interest in physics has been consistently low in the last four decades and aspiration to become a research scientist is declining in popularity.<sup>15</sup> Despite demographics doesn't directly affect students' learning performance,<sup>156;157</sup> i.e., majority and minority students can have similar grade scores, women and minority still leave STEM,<sup>158-160</sup> indicating the performance or competence alone don't predict the career choices.<sup>11;15;103</sup> A large body of research, therefore, is dedicated to investigating hidden variables that might influence students' career intentions.

Throughout education research on career-related topics, contributing variables have been

brought from almost all contexts in one's life that can have an effect on career choices, ranging from academic factors, i.e., self-efficacy, interest, recognition, performance, sense of belonging, stereotype threats, research experiences,<sup>19;103;104;106;161–164</sup> to sociocultural experiences such as gender, social economic status, and social identity.<sup>121;165–168</sup> Recently, scholars have expanded the discussion on out-of-class experiences through informal programs and outreach to also impact on students' career choices.<sup>11;169</sup>

Despite evidence that a variety of factors influence students' career choices, scholars have paid little attention to discussions of how students reflect on and navigate their academic and sociocultural experiences, as well as how they integrate these experiences into students' professional identities (detailed in next section). We argue that identity exploration is a process of becoming rather than an end point or a destination.<sup>170</sup> The process of visualizing future and putting oneself into their future is complex, necessitating many reciprocal linkages that account for both intrapersonal factors and future career characteristics such as income, geography, climate, traffic, and so on. While acknowledging all previously studied variables, this study uses the Possible Selves Theory and multiple case studies methodology to develop an in-depth understanding of not only the impact of intrapersonal and environmental factors on professional identities, but also a process of exploring and refining their future possible selves. The findings of the study can assist policymakers in incorporating students' needs into undergraduate programs in order to support and retain future STEM workers.

## 5.2 Background

Choosing a career is a complex process because it requires navigating and balancing various aspects ranging from the personal (e.g., personal interest, passion) to the societal level (e.g., neighborhood, demographics, living expenses, traffic.) Thus, the occupational decision is a result of a reciprocal linkage from multiple directions, rather than a single factor. An article reviewing literature on career-related studies conducted by Tuijl et al.<sup>171</sup> suggested that some important aspects of career development are set on interest, enjoyment, value, and self-efficacy. Two theoretical models that have been widely used to date to examine

students' career development: the Social Cognitive Career Theory (SCCT)<sup>172</sup> and Identity Theory<sup>104</sup> have encompassed various factors that either support or inhibit students' career development. This section consolidates important conceptual understanding from these two theoretical constructs as well as from prior studies to pinpoint core variables and mechanisms behind students' career development. The section is divided into two primary categories: academic and sociocultural variables.

### 5.2.1 Academic variables

Self-efficacy, defined as people's belief in their ability to succeed in a domain,<sup>173;174</sup> has received a lot of attention in education research. Not only does self-efficacy influence occupational consideration,<sup>172;175–177</sup> but it also influences students' academic performance,<sup>178–180</sup> identity development,<sup>19</sup> and retention.<sup>163;181;182</sup> Lent et al. expanded on the general concept of self-efficacy to create a theoretical model aimed at understanding the process of making career-relevant decisions.<sup>172</sup> The correlation between self-efficacy and career behavioral choices is strongly supported by empirical data.<sup>177;183</sup>

Another key variable in career-related research is interest, which is defined in the context of physics as the “desire/curiosity to think about and understand physics.”<sup>104</sup> Drawing from the social-cognitive career model,<sup>172;184</sup> Hazari et al. included interest as a critical component in developing physics identity,<sup>104</sup> which influences the decision of who a student wants to become.<sup>103</sup> Prior research has identified two primary consequences of interest. Either a strong interest leads to a major or a strong interest leads to a career. These two objectives are not always the same. For example, Adams et al.<sup>185</sup> discovered that “personal interest” in physics can lead to a choice of physics as a major. This differs from Lock et al. showing that the interest is related to choosing physics careers.<sup>186</sup> Nonetheless, a strong interest in a discipline leads to a desire to continue pursuing it. It is noted that self-efficacy and interests are strongly correlated and are co-construct to predict one's academic achievements and career aspirations.<sup>19;187</sup>

Undergraduate research experiences and internships also influence career choices. A large

body of literature has consistently found numerous benefits of engaging students in authentic science research work, such as acquiring knowledge and skills outside of the classroom, improving employability, and motivating students to pursue further learning at the graduate level, which can act as a pathway for students into science careers.<sup>7-10;188</sup> Hunter et al. stated that undergraduate research treats students as members of the scientific community and involves students in the process of “becoming a scientist,”<sup>6</sup> which is strongly predictive of STEM career paths.<sup>7</sup> This concept has been validated in physics education. Irving et al. and Alae et al. both highlighted the role of doing research as an undergraduate student, either in-person or remote research, in developing physics identity,<sup>138;189</sup> consequently inspiring students to pursue physics-related careers in their future.<sup>186</sup>

Recently, scholars have extended the scope to conclude the significance of out-of-school experiences and extracurricular activities in shaping students’ career intentions.<sup>11;169;190</sup> Godwin et al. found the likelihood of choosing a career in a particular engineering discipline was influenced by out-of-school experiences such as tinkering with electrical devices or watching science fiction.<sup>12</sup> Findings from a physics context revealed a similar effect, in which tinkering with mechanical or electrical devices all related to physics identity and further physics career choices.<sup>11;191</sup>

### 5.2.2 Sociocultural variables

A substantial body of literature on career development has theorized and empirically tested the influence of sociohistorical and sociocultural contexts on career perceptions. Lent et al. proposed, based on the social-cognitive career model, that the extent to which an individual envisions their future career is partly informed by the cultural values and norms to which they have been exposed<sup>10</sup>. Agreeing with the Lent’s proposal, prior studies have found gender, race, ethnicity, and socioeconomic status all influence whether some careers are perceived as appropriate and accessible to pursue.<sup>165;192;193</sup>

There have been numerous studies to date reporting the observation that female students believe science is innate and exclude STEM-related options based on negative images from

a young age.<sup>121;166;171;194</sup> Male-dominated fields are stereotypically labeled with traits that women do not typically possess, resulting in an incongruent threat of who is capable of pursuing science.<sup>192</sup> Some evidently gendered professions include computer scientists stereotyped as “computer nerds” who are socially awkward,<sup>195</sup> and physicists stereotyped as “always male, somewhat disheveled.”<sup>196</sup> Such images foster a misbelief that being a woman affects the capability of performing a science task.<sup>161</sup> In a similar context, Nosek et al. found that even women in math-intensive majors still showed more negativity towards math than men did because “*math = male, me = female, therefore math ≠ me*”.<sup>121</sup> Women’s careers in science have thus been limited in part as a result of such misconceptions and stereotypical images that society has incorrectly imposed on them, but which have become internalized and subsequently translated into career choice behaviors.

Family appears to be another sociocultural context to influence occupational aspirations and career development of children.<sup>19;191;194</sup> The Identity Control Theory asserts that day-to-day interaction between young children and their parents can either support or challenge an adolescent’s existing identity as well as their belief about what is possible for their future career.<sup>197</sup> Scholars have strengthened the connectedness between parental support and students’ identity-shaping process by empirical data. For example, Li et al. found the connectedness between parents and daughters increased women’s distress about future careers, leading to the willingness to switch choices to fit their parents’ expectations while the separateness from parents was associated with less identity disruption.<sup>168</sup> Another relevant study conducted by Godwin et al. showed that a family member’s profession was predictive of engineering career choice after controlling for students academic performance, and socioeconomic status.<sup>198</sup>

Although all these variables have been classified in the distinctive categories, they are all interconnected. Self-efficacy is a dynamic trait that changes over time and is affected by sociocultural factors. For example, Zeldin et al. found that women often rely on social persuasions such as family and peers to construct self-efficacy.<sup>177</sup> On the other hand, family can be perceived as either a source of support or a source of impediment to students’ interest in a discipline or self-efficacy, which in turn can predict career intentions. The interdependence

of variables reflects the complexities of one's identity development process, which integrates factors and supports from multiple sources to determine their future careers.

To summarize, the well-established literature on career-related research has provided an insightful picture of contributing factors to students' career development. However, two major concerns deserve further research. First, "career intention," "career choice," "career development," and "occupational consideration" are all interchangeably used throughout literature. We argue that a distinction is necessary and explain why it necessitates separate research for career choice and career intention. While "career intention" may simply indicate a preview of a field or domain in which students wish to pursue a career (e.g., an intention to work in a STEM-related field), "career choice/decision" requires a specific and refined decision about which job to take (e.g., becoming an engineer in a software company X or a faculty at a university Y). In physics education, the terms "career intention" and "career choice" are also used interchangeably, and both are commonly measured by asking students to rate the extent to which they view themselves as "a physics person" or as choosing a career in physics.<sup>11;104;186</sup> However, we argue that there are numerous occupations that can be considered as a physicist, such as a physics faculty, a physics high school teacher, a medical assistant operating an X-ray machine in a hospital, or a postdoctoral researcher in a cosmology research team. While identity exploration is a process of becoming rather a end point,<sup>170</sup> there is little discussion throughout literature on the process of exploring, adjusting, and refining one's career intention preview. This study, therefore, attempts to address two research goals: (i) determining influential factors to career choice, (ii) examining a process of refining their career choice. Second, despite research demonstrating how much each of the aforementioned variables contributes to career development, most studies have primarily focused on quantitative aspects of contributing factors, without allowing participants to reflect on their own academic and sociocultural experiences to provide an insightful understanding of their professional identity formation. Thus, the nature of how and why academic and sociocultural factors interact with professional identity, as well as how participants strategize their actions and plans to acquire career goals, has gone unexplored. This limitation has been acknowledged in many quantitative studies.<sup>169</sup> This project is intentionally designed to

allow participants to express themselves with the goal to discover in-depth understanding of how individuals' academic and sociocultural experiences interact and play out in future career thinking.

To achieve these two research goals, we employ the Theory of Possible Selves as a theoretical guide.<sup>199</sup> Competitive theoretical frameworks, the Social Cognitive Career Theory (SCCT)<sup>172</sup> and Identity Framework,<sup>104;106</sup> are not chosen due to some reasons. First, the Identity Framework specifically targets disciplinary identity such as physics or science identity, whereas our emphasis is more on professional identity, which should encompass both students' reflection on their disciplinary capacity and imagination of future roles. Second, neither theoretical model takes the navigation of multiple identities into account. We argue that when people are thinking about their future identities, they are likely to imagine themselves in multiple roles at the same time, such as being a physics professor but also a learner in an education community conducting education research. For these reasons, the Theory of Possible Selves is chosen as it allows participants to construct multiple imagined roles and inhabit them concurrently. The next sections detail the theoretical concepts of the theory and explain how the theory helps us achieve the research goals.

### 5.3 Theoretical framework

Possible Selves Theory is an identity theory referring future-oriented self-representations.<sup>200</sup> According to Markus and Nurius, future possible selves (FPS(es)) are conceptions of "how individuals think about their potential and about their future" including what they would like to become, what they could become, and what they are afraid of becoming. FPS(es) are not only just a set of roles and developed in abstraction, they carry hopes, fears, fantasies as well as plans and strategies to either achieve or avoid some certain possible selves. For example, a student who wants to become a theoretical physicist (role) but has failed a quantum physics course might carry with her/him some fears such as not graduating, not getting into a grad school. Based on empirical data about people's perceptions of what future life might look like, Markus and Nurius theorized that we all hold a range of possible

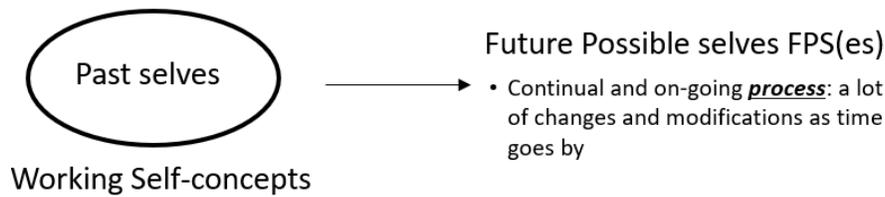
identities and representations of ourselves as we might be days, months, years hence. Thus, within a given moment, one can envisage multiple future possible selves, either positive (hope-for selves) or negative (feared selves).

The concept of FPS(es) is important because it serves two functions: first, it serves as a motivational role or incentive to guide future behaviors; and second, it serves as an interpretive and evaluative context for the current view of self. In terms of the first function, possible selves such as hope, aspiration, and happiness plan future behaviors to achieve them, whereas possible selves such as tragedy and threats plan future actions to avoid them. Markus described this function of possible selves to “represent motives by giving specific cognitive form to the end states (goals and threats), to the associated plans or pathways for achieving them” (p.961). In addition, possible selves acting as incentives can subsequently increase one’s self-efficacy and creativity in the achievement of their goals.<sup>201</sup> A student constructs positive possible selves, such as graduating with a high GPA and landing an international internship. A high GPA and an internship as an incentive motivate the student’s future behavior, i.e., studying hard. The second function of possible selves is to provide the context to interpret the meaning of the current self. For example, the student with a possible self of becoming a physicist will attach a different interpretation to a grade of A in engineering physics than someone without this possible self.

The construction of FPS(es) is based on one’s past experiences.<sup>200;202;203</sup> Erickson argued that the possible selves construction is a meaning-making process where we find self-relevant ways to make the future selves commensurate with who we were.<sup>204</sup> The successful possible self in academia, for example, may be informed by the past self of “I have always been a good student in my class.” The feared self of being unemployed in the future may be linked to the negative past self of “I was expelled from school once.”

However, not all past selves are available for thinking about the FPS(es). According to the theory, only past and current selves that are currently active and accessible to the working self-concept contribute to FPS(es) construction. The working self-concept, a broader work in the discipline of psychology, is viewed as a storage of thoughts and memories that are available and active in individuals’ minds to build up self-images for futures. For example,

a person's collection of self-conceptions may include both good and bad past selves (being a good student, receiving a scholarship, doing charity) (being betrayed, losing a friend). However, not all of these past selves are active in the working self-concept to construct career-related FPS(es). Perhaps, being a good student and receiving a scholarship may be two past selves that have remained most active to translate into a possible self as a graduate student. Fig. 5.1 summarizes some key concepts of the Possible Selves Theory.



**Figure 5.1:** *FPS(es) are influenced by one's past selves that have remained active in the working self-concept*

Prior studies that applied the Possible Selves Theory to an educational setting specifically explored what past selves most significantly impact career-related possible selves and discovered a strong association between academic variables and FPS(es) development. Markus et al., in agreement with the literature on self-efficacy and career choices, highlighted self-efficacy as an integral component that was strongly related to specific, well-envisioned possible selves. The importance of self-efficacy in one's possible selves also has been accounted for in Expectancy-value Theory and SCCT.<sup>172;205</sup> In addition to self-efficacy, extracurricular activities, internships, intensive academic programs, and mentorships are all academic contexts in which students can explore and negotiate career-related possible selves.<sup>206;207</sup>

As indicated in theory, FPS(es) can act as incentives to motivate the current behaviors. Empirical research has shown that students who have well-developed possible selves perform better academically, persevere longer on tasks, and are more motivated than those who do not.<sup>208</sup> In contrast, a study conducted by Yowell showed that Latino students who had feared selves of not being able to finish high school, being unemployed, or having family members as gangs, were more likely to drop out of schools.<sup>209</sup>

Possible selves are highly personalized, but they are built within a sociocultural context

that influences which selves appear probable or desirable.<sup>209-214</sup> Harrison stated that the extent to which individual's values about what selves are to be viewed as appropriate is informed by class, gender, and ethnicity.<sup>203</sup> Furthermore, sociocultural contexts influence how one's social experiences occur, such as who we meet and where we study. Thus, different social groups will have very different perspectives on what is desirable and probable. According to research, there is a disparity in the construction of the future between major and minor groups of students. Young people from middle-class backgrounds, for example, develop their FPS(es) through instructional strategies cued by teachers and parents, leading them to expect a graduate degree and a prestigious future possible career.<sup>215;216</sup> Contrasting with middle-class contexts, minority and low-income children express positive possible selves as conflicting with their social status.<sup>210;215</sup> Oyserman et al. confirmed that unless possible selves are connected with social identity, the possible selves alone are not well-developed.<sup>210</sup> For instance, when physics students ask themselves if they can become a graduate student, they not only wonder about their perceived capability but also their social identity (i.e., Can people like me join a grad school to become a physicist?).

Additionally, Pizzolato emphasized that becoming a college student is a novel possible self to students of color from low-income communities.<sup>212</sup> Thus, they not only need parental encouragement but also need ongoing guidance and access to resources about how the application and admission process work in order to achieve hope-for college possible selves. Another student conducted by Garcia et al. found both ethnic and gender difference in perceiving the probability of possible selves and in self-efficacy.<sup>217</sup> Thus, young women may consider science possible selves not to be a good fit for them because of extensive systematic sexism in science,<sup>207</sup> resulting in a gap between female and male students in science-related possible selves.<sup>214</sup>

To conclude, FPS(es) are the future tense of our self-concept, representing our current perceptions about who we want to be in the future. The construction of FPS(es) is inextricably linked with one's past selves remaining active in the working self-concept, i.e., what we expect about the future is dependent on what we were like in the past. Importantly, sociocultural contexts influence what is possible and desirable in the future. Multiple pos-

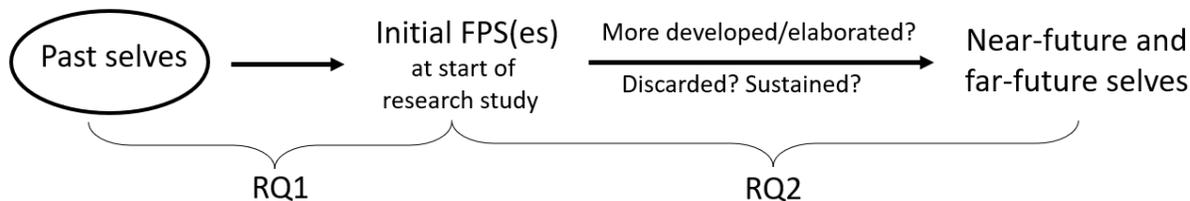
sible selves can be imagined at the same time, but they are not static; they can be revised and changed over time depending on one's internal states and social circumstances. As time passes, some may appear to be positive and worthwhile to pursue, while others may appear to be negative and should be avoided.

While previous studies have contributed to our understanding of what influences students' possible selves, the majority of them has been conducted on adolescents.<sup>207;209;210;218;219</sup> There is little discussion in higher education settings, particularly as college students near graduation.<sup>170</sup> Furthermore, similar to the need for a distinction between "career intention" and "career choice/decision," we contend that FPS(es) can range from a broad overview (e.g., staying in physics) to a more specific self (e.g., joining a research group doing cosmology at the University of X). In order to achieve a career, ones must narrow down their career previews to specific plans and actions. The process of refining, adjusting, and revising broad images of selves is unexplored in the literature. This study, therefore, conducts longitudinal interviews (first and follow-up interviews) and uses the context of the Theory of Possible Selves to examine the FPS(es) development with two research goals : (i) applying the Theory of Possible Selves in the context of higher education, particularly for seniors and recent alumni, to develop an understanding of how possible selves are developed in tandem with students' past selves, (ii) investigating the process of change or elaboration of their initial FPS(es).

Two research goals are depicted in Fig. 5.2 and formalized in the following research questions:

1. How do students bring their past selves to develop future professional possible selves?
2. What is the nature of future professional possible selves paths during the transition from pre to post graduation?

It is important to highlight the scope of this study. As noted in Fig. 5.1, FPS(es) are more of a process than a static property at a given time point.<sup>207</sup> Indeed, as people have gained more life experience, FPS(es) have undergone numerous changes and modifications. Individuals' entire lives may be required to fully capture and comprehend FPS(es). As a



**Figure 5.2:** A diagram that maps out 2 RQs. RQ1 focuses on past selves and RQ2 examines the process of change or elaboration of initial FPS(es)

result, the goal of this work is not to fully capture and interpret FPS(es) throughout the lives of students. Rather, we provide a small window (from the first to the second interview) as an example of exemplifying the process of changing and refining FPS(es). Terminologies in Fig. 5.2 and throughout this chapter are explained as follows. We categorize FPS(es) into three primary groups: initial FPS(es), near-future selves, and far-future selves. *Initial FPS(es)* encompass a broad overview of professional careers mentioned by participants at the beginning of research study (via the first interview), which is equivalent to the previously mentioned “career intention.” Initial FPS(es) can simply be an overarching idea of which discipline students want to pursue as a career (e.g., physics, computer science, math), rather than a refined or specialized decision of what happens next. As participants gain more experiences in both academia and life, initial FPS(es) are refined and adjusted, resulting in *near-future selves*, which represent the next professional event. Because identity exploration is a dynamic and ongoing process, rather than an end point, near-future selves will continue to envisage who they will be in the far future or *far-future selves*. To elaborate on our terminologies, an initial FPS is building a career in physics; near-future selves include going to grad school at the university X and doing research in cosmology; we say that these near-future selves are refined and narrowed from the initial FPS. Consequentially, these near-future selves will continue to imagine far-future selves as becoming a tenure-track faculty at a R1 university or working in NASA after grad school, these far-future selves are commensurate with the initial FPS.

## 5.4 Methodology

### 5.4.1 Data selection

The context and data collection of this study is presented in chapter 3. Out of 19 interviewees, we were particularly interested in four students: Molly, Francisco, David, and Ricky (pseudonyms) (Table 5.1). All these students participated in longitudinal interviews. The first interview was conducted a few months before David, Francisco, and Ricky graduated. The follow-up interview took place after 6 months. The first criterion to filter out the data is the graduation timeline. We were particularly interested in the data cohort's eight senior students, arguing that the time leading up to graduation was the most intensive for students, as they needed to figure out what would happen next in their lives. Thus, we hypothesized that seniors had been deeply involved in the process of identity exploration, resulting in complex stories. We did have Molly as an exception. Although classified as an alumna, Molly had just graduated for 2 months and had been searching for her next step by the time of the first interview. Thus, we put her into the group with seniors.

The second criterion for selecting data is our impression on students' possible selves after preliminary examinations. Students who developed multiple distinct possible selves, planned to switch to another domain, or joined an interdisciplinary domain attracted our attention. In comparison to a physics student planning to become a physicist, a physics student planning to become a software engineer can pinpoint some hidden patterns that need to be investigated. A switch to another domain can indicate that either students do not persist in physics or the physics program well prepares students for multiple career paths. Thus, exploring these possible selves are specially important in assisting students in building future careers.

Based on these two criteria, we ended up going further with Molly - switching to software engineering, Francisco - having an intense introspection to pick one possible self and reject another one, Ricky - joining medicine, and David - remaining doing physics education.

**Table 5.1:** *Data corpus*

	Molly	Francisco	David	Ricky
Pronoun	She/her	He/him	He/him	He/him
Year	Alumna	Senior	Senior	Senior
Race/Ethnicity	White	Latino	White	White
Majors	Triple major in physics, math, and philosophy	Double major is physics and math	Double major in physics and math	Double major in physics and math

### 5.4.2 Data analysis

Among qualitative methodologies, we determine multiple case studies as the best method for our research design. Given the prior theoretical proposition and literature review on career-related studies, case study methodology is especially appropriate for researchers to account for prior findings and develop in-depth understanding and descriptions based on each participant’s contextual conditions.<sup>146</sup> Case study research involves the study of a case within a real-life, contemporary bounded system (a case) or multiple bounded systems (cases) through detailed, in-depth data collection such as interviews, reports, or documents.<sup>147;220;221</sup> Merriam highlighted that the determination of what a case is depends on the interest of the researcher.<sup>222</sup> A case can be a concrete entity, such as an individual, a small group, an organization, or a partnership. Additionally, theorists on case studies stated that the goal of case studies is not to find the correct or true interpretation of the facts. This is because no matter how much we try, we cannot capture the whole.<sup>147</sup> What case studies do is to at best, document “what we are able to understand, gather, interpret, analyze, in the moments of time we have shared with the participant and are invested in reporting the result of our inquiry” (p.110).<sup>147</sup> Thus, the intention of the case study is “not for generalizing beyond the case, but for understating the complexity of the case” (p.101).<sup>220</sup> As described in detail in Chap. 4 and Sec. 4.4.2, we acknowledge that students’ perceptions of their FPS(es) are legit to them only as individuals and are not intended to generalize as the objective truth about

FPS(es) development.

The analysis substantially followed guidance of case study from Creswell(p.98)<sup>220</sup> and Bhattacharya (p.111)<sup>147</sup> to build up our systematically analytic strategy. We first defined the bounded system of study: each student is a case study, and an issue to investigate within each case is developing possible selves based on one's past selves informed by academic and sociocultural experiences bounded by that case. Our identification was influenced by our theoretical perspective, focusing on the identity of individuals informed by their own self-conceptions of who they are. Thus, it made the most sense to develop an in-depth understanding of each person's identity instead of a group or an organization. We then determined the intent of the study was to report multiple case studies with a cross-case comparison. As multiple case studies were chosen, there were two steps of the analysis. The first step was within-case analysis, which detailed the description and themes within the case. The second step was cross-case analysis, which identified similarities and differences among cases. The finding section (see Sec. 5.5) presents within-case analysis and also intentionally use comparing language (e.g., similar to, in contrast to, as opposed to) to emphasize cross-case analysis.

To answer two RQs, we began by reading through two interview transcripts of each participant and marked all evidence of FPS(es) mostly informed by the career planning and factors section in the interview protocol. FPS(es) were first identified by keywords that indicated a field, a domain, or a profession. While identifying FPS(es), FPS(es) were arranged on a timeline and categorized FPS(es) into three major groups: initial FPS(es) obtained in the first interview - an overall intention of future careers; near-future selves obtained from the second interview - the next professional event that is expected to be more specialized and refined from the initial FPS(es); and far-future selves obtained from the second interview - imagined selves in the far future. Collecting these three components of FPS(es) and arranging them on a timeline invoked the answer for RQ2. According to the theory, FPS(es) are more than just the names of professions or fields; they are also incentives and fears associated with the profession. Thus, while collecting FPS(es), we also paid attention whether students described incentives or fears with their FPS(es). For

example, becoming a physics faculty is a FPS. Associated with this FPS, the student sees herself/himself earning a good income, starting up their own lab, and having international collaborators. These components are coded as incentives to motivate students' behaviors. In contrast, some potential perceived barriers (fears) associated with a self as a physics faculty are competitiveness, pressure from funding, and maintaining high-end research. Thus, a complete picture of FPS(es) is characterized by: initial FPS(es), near-future selves, far-future selves, and incentives as well perceived barriers associated with selves.

RQ1 was answered by relying on prior studies to determine students' past selves in the light of their academic and social experiences. Guided by the Theory of Possible Selves, the past selves mentioned by students by the time of the interviews were considered as active in students' working self-concepts (the circle part in Fig. 5.1 and 5.2). We read through two interview transcripts of each participant to code past selves and classify them into two primary categories: academic factors and sociocultural factors. The explicit evidence of academic and sociocultural factors emerged from the data itself.

After our within-case preliminary analysis, we noticed similarities and differences among case studies, referred to as cross-case analysis. We noticed different past selves that each case brought into their FPS(es) development, as well as two paths by which participants refined and elaborated on their initial FPS(es). To communicate the findings, we grouped David, Ricky, and Francisco together because they all followed a similar FPS(es) path, whereas Molly followed a significantly different one. The following sections describe how each case study developed their FPS(es) in tandem with their past selves, taking into account the similarities and differences between case studies.

## 5.5 Findings

There are two major findings according to each research question. Regarding research question 1, four case studies developed well-elaborated possible selves in which students had a clear sense of who they want and don't want to become. Each possible self was developed in association with students' past selves, as informed by their academic and sociocultural

experiences. In particular, positive experiences from coursework, research, and conferences supported students to develop the strong interest and self-efficacy in a discipline/field, resulting in FPS(es) development in the field. However, consistent with prior study, negative experiences such as not being valued by peers might reduce students' self-efficacy, sequentially sabotaging FPS(es) in the field. Personality, living habits, and social identity were also incorporated in order to make future selves congruent with sociocultural experiences.

In response to research question 2, we observe two FPS(es) paths that students took to refine their initial FPS(es): a narrowing path and a sequenced path. Students who chose the narrowing path first developed initial FPS(es) in a career area and over time students developed more specialized selves in that career area (Fig. 5.4, 5.6, 5.9). The second path, as seen in Molly (Fig. 5.10), contrasts with the narrowing path in which she tried different FPS(es) in different career areas in series until she determined what worked the best for her. This section details the findings of two research questions. Although Ricky, Francisco, and David shared common patterns in the their FPS(es) development and refinement, each case study had some distinguishing characteristics that prompted us to present it separately. As a result, we present our findings one case study at a time, incorporating findings from both research questions.

Given the characteristics of case studies as a methodology described in the previous section (Sec. 5.4), we highlight how case studies control some important features of our findings. Findings of case studies are not intended to be generalized. As mentioned by Bhattacharya<sup>147</sup> and Creswell,<sup>220</sup> researchers try best to interpret what they observe in the case or cases and understand the complexity, rather than try for an unified conclusion about the phenomenon that the researcher is investigating. Thus, here we assert that academic and sociocultural factors, as well as two primary paths to refine initial FPS(es) determined by the four case studies do not represent the whole phenomenon (possible selves development). Rather, we argue that our phenomenological patterns observed in one case study or multiple case studies can potentially be observed again in other students. Thus, though findings aren't generalizable, they are useful in understanding the significant factors and ways in which students' future careers are constructed or inhibited.

### 5.5.1 A narrowing path of refining and elaborating on initial FPS(es)

#### Ricky

Ricky (he/him) was a senior and double major in physics and math/computer science. By the time of the first interview, Ricky had two more quarters left to graduate and intended to “take physics knowledge and apply it to medicine.” More specifically, Ricky wanted to “apply to grad school” and “continue into a PhD program next year.” “Medicine,” and “applying to grad school” were coded as Ricky’s initial FPS(es) at start of the study. Six months later when he took the follow-up interview, Ricky had accepted a grad school offer to do a PhD in biomedical engineering (coded as Ricky’s near-future self). This near-future self enabled Ricky to continue envisioning a far-future self as working in industry and creating medial devices. Fig. 5.3 highlights primary Ricky’s past selves that influence his FPS(es) in medicine. Fig. 5.4 presents a narrowing path of refining his initial FPS(es) over time.

**Past selves informed by academic driving factors** Participating in conferences and attending research are two most significant academic experiences that translate into Ricky’s possible selves in medicine. Ricky recalled conferences through which he began the journey of pursuing medical physics: “About a year ago, in October 2019, I was at Phys Con conference and the SACNAS conference, and I met a bunch of medical physicists, and I kind of learned about this new branch of physics that is medical physics” (Ricky). Besides exploring the existence of the field, conferences brought an opportunity for Ricky where he “has interacted with, emailed, and been on Zoom calls” with an alum who gave a colloquium talk in SACNAS conference and who is now practicing medical physics. This alumnus has been “a mentor” who helps grow Ricky’s interest and understanding of the field over time. The participation in conferences not only helped Ricky discover the existence of medical physics but also exposed him to experts from different places where he could seek help to grow his possible selves: “Some of those conversations [at conferences] have led to emailing back and forth months after the conference is over, this is helpful and I need this and having a conversation about this journey” (Ricky). Ricky acknowledged the contribution of conferences

to discovering his possible selves in medical physics: “What has been most impactful to my trajectory is going to the conference for the idea of what I wanted to do” (Ricky). “Being in a conference environment” also provides Ricky an idea of “this is what a career in this looks like.” We noticed that Ricky constantly mentioned his participation in different conferences through which he discovered an interest in medical physics in both interviews, indicating the significant contribution of conferences to his FPS(es) in medicine.



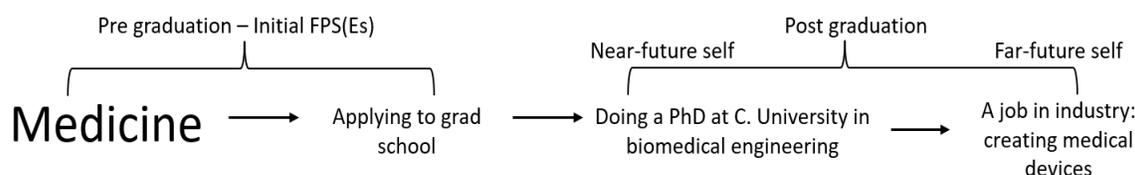
**Figure 5.3:** *Ricky’s past selves influence the development of FPS(es) in medicine*

Research experiences in material science also helped Ricky shape possible selves in medicine. Ricky “[has] had two undergraduate research experiences and they were all in material science. One of the works was the start of a project to find a better solar panel material that could be transparent and then applied to skyscrapers downtown.” Ricky perceived material research to be “vital and important,” however he wanted his possible selves to make a direct impact on people everyday while working in material science takes time to see an impact: “[Material sciences] are obviously really great and interesting, but I wanted my work to have more of a direct impact...And so that intimate connection and intersectionality between the research work and patients’ lives is what brought me interest into [medical physics]. My reason for wanting to do that is because it’s so important it can impact peoples’ lives in such an immediate and meaningful way” (Ricky). In this case, the impact on people’s life acts as an incentive to reinforce Ricky’s choice for his possible selves in medicine. Ricky also acknowledged that “skills of finding materials and optimizing properties from material sciences is completely directed to medical physics” and helped him determine a possibility to enter medicine, saying: “I found a different branch of medicine that fit my interests more than what I thought. There’s not only one path in medicine, but there’s obviously many. I found one that works for me” (Ricky). We conclude that engaging in research inspired

Ricky to start thinking about a possible self who will work in medicine and have an impact on people’s lives.

In summary, past selves of attending conferences and engaging in research were positive academic experiences that inspired Ricky to construct FPS(es) in medicine field. We conclude that conferences and research are two significant academic contexts through which Ricky’s FPS(es) in medicine are developed.

**Past selves informed by social driving factors** The choice of FPS(es) in the medical field was “the intersection of many things.” He recalled: “I’ve always been interested in health from a young age. I remember my dad would take me to the health store, protein, smoothie shop, we’d go there and get wheatgrass shot. It was one of those life defining moments” (Ricky). At first, it was “just like a habit to do healthy things, and over time, that grew into [Ricky].” Ricky started thinking more about “what should be eating to be more healthy,” he “[has] never gone to Mcdonalds, [he doesn’t] drink soda a lot.” Over time, taking care of his health “became a part of [his] personality” and was integrated into his thinking of a professional future, leading to a realization that “wait, there’s a whole field of physics where you can take those interests and improve health care for many people.” “All of that coming together was perfect for [Ricky]” where he can do physics to improve health for himself and people. We conclude maintaining healthy lifestyle is Ricky’s social experiences in conjunction with academic experiences that impacts the development of FPS(es) in medicine.



**Figure 5.4:** A narrowing path taken by Ricky to refine and elaborate on his initial FPS(es)

**Ricky’s near-future and far-future selves** The follow-up interview was conducted after 6 months to check in with Ricky’s initial FPS(es). By the time of the follow-up interview, Ricky recently graduated and was heading to a graduate school in biomedical engineer-

ing (coded as Ricky's near-future self): "I'll be going to C. University next year to study biomedical engineering. I wanted to take my undergraduate majors, I was interested in how I could relate to the medical field and doing medical research, and so that's how I landed at biomedical engineering" (Ricky). In addition, the near-future self in biomedical engineering continued envisioning a far-future self in medicine: "I can take [biomedical engineering degree] to industry to create these medical devices in general terms and bring them into the operating room to hospital to really make a difference" (Ricky) (coded as Ricky's far-future). Throughout the follow-up interview, we noticed that Ricky again constantly brought up conferences as an eye-opening moment that inspired him to start thinking about a future self in the medical field, his research experiences that set him up as a scientist, his habit to "treat the body right and eat healthy foods," and the incentives that his possible selves can "change outcomes in the medical field and improve people's lives."

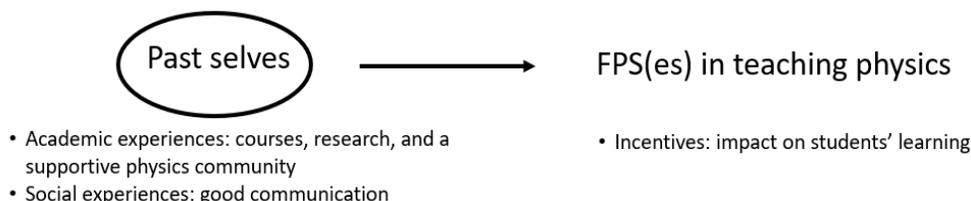
Overall, Ricky's past selves of engaging in research and conferences, along with his healthy habits influenced him to develop initial FPS(es) in medicine. Throughout Ricky's identity exploration, he took a narrowing path that began with "applying to grad school" and then settled in "C. University next year to study biomedical engineering." This near-future self enabled Ricky to continue envisioning a far-future self working in industry to create medical devices and make differences for the future society.

## **David**

David (he/him) was a senior and double major in math and physics. By the time of the first interview, David had two more quarters left to graduate and determined his FPS(es) to be teaching physics. Although David "[had] been debating if [he wants] to devote the next six years to get a PhD and then teach at university level versus getting certification and teaching at a high school level very shortly," David narrowed down to "going to grad school, so continuing in physics education research and going to get [his] PhD" in order to teach "upper-division physics courses." Thus, teaching physics and applying to grad school were coded as David' initial FPS(es). Six months later when David took a follow-up interview, he

accepted an admission letter to do a PhD at V. University in PER (coded as a near-future self). This self continued envisioning a far-future self as a physics professor who will teach upper-division physics classes. Fig. 5.5 summarizes David’s past selves that influenced his FPS(es) in teaching physics. Fig. 5.6 highlights a narrowing path of refining David’s initial FPS(es).

**Past selves informed by academic driving factors** The next step of getting a PhD in physics education research as the next step was strongly influenced by David’s research experiences. Talking about research, David said: “It’s wonderful. I love doing research. My last research, I focused on the experience of LGBT+ physicists and how the workplace impacts their outness as well as their performance at the job. We have submitted a paper” (David). Later on, David expressed that research in physics education allowed him to both “share knowledge” and “get to continuously advance knowledge as well as learn about students.” Thus, we conclude that past selves of engaging in research influenced David to develop a FPS who will be involved in students and continue to do research.



**Figure 5.5:** *David’s past selves influence the development of FPS(es) in physics*

Another academic contexts that helped David to develop his possible selves in physics were physics courses and content. David “was developing an extreme interest in the material.” To David, “statistical mechanics or quantum mechanics were extremely interesting and something that [he enjoys],” and “quantum mechanics is one of the best things in this world. [He is] a big fan. [He really enjoys] upper level physics and that’s part of why [he thinks he should] go to grad school.” In addition, David perceived himself to be good at physics and good communication (high self-efficacy) in order to teach: “Being somebody that’s very good at physics and I have good enough ability to communicate thoughts as well

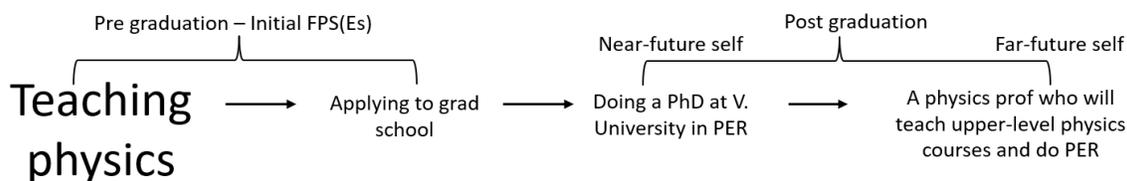
as communicate materials with others. What I'm doing now and what I'm learning, I can transfer to others and I can impact others" (David). It was evident that through courses and physics content, David developed a strong self-efficacy in his physics knowledge, as well as interest in upper-division physics courses, where he named quantum mechanics as "one of the best things in the world," influencing David to go to grad school to continue exploring physics through which he could use his knowledge and skills to teach.

The support that David received from the physics community was another academic factor that inspired David to continue higher education in grad school: "I think one of the experiences I've had that's helped to shape my vision of the future is having such a tight knit community. In this community, we try to give each other support. Part of it is in the physics department we all know what everybody else is doing, there is interconnectedness. I definitely wouldn't be doing PER if I wasn't at D. university...If I hadn't been exposed to others that are now in grad school and succeeding, or even the ideas of going to grad school and succeeding and seeing people who have done, I think I might not possibly be applying currently" (David). Based on these narratives, we conclude that the supportive community added to David's consideration to go to grad school.

Summing up, past selves of being good in physics classes, engaging in research, and being a member of a supportive community were positive academic experiences that inspired David to construct FPS(es) in physics as a career area. We conclude that conferences, research, and a supportive community are significant academic contexts through which David's FPS(es) in physics are developed.

**Past selves informed by social driving factors** David also involved social factors into his possible development. Being a teacher worked for him because "[he likes] to talk a lot" as a person. Teaching students can allow him to interact and talk to students. In addition, as mentioned earlier, David perceives himself not only as "very good at physics" but also "have good enough ability to communicate." Thus, David was coded as having high self-efficacy in both physics and in communication, which can strengthen his FPS(es) to become a physics teacher.

Similarly to Ricky, David thought of the impact that a possible self as a physics teacher can offer to society. The positive picture of becoming a physics teacher acts as an incentive to strengthen David’s choice: “When thinking about careers, the type of work that I would be doing such as the impact, like working with students. I think about how I can transmit [knowledge] to others and how I can impact others” (David). Explaining the choice of teaching, David wanted to teach because “[he loves] helping and [he loves] the material.” While to Ricky, working in medicine can have an immediate impact on people’ health, to David, teaching is helping, sharing the materials to others and thus, having an impact on students. We conclude that to Ricky and David, the development of possible selves involves the positive impacts that the possible selves can contribute to the society and community.



**Figure 5.6:** A narrowing path taken by David to refine and elaborate on his initial FPS(es)

**David’s near-future and far-future selves** The follow-up interview with David occurred after 6 months. At this time, David graduated and was going to physics graduate school to continue physics education research in about one month and a half (coded as a near-future self). In this interview, David redeclared his interest in teaching, how research influenced his decision to go to grad school, and the impact that he wanted to have on the community through teaching students. To David, the practical impact is “share knowledge with others so that they can learn as well.”

David was no longer wondering about teaching high school or university, which he narrowed down to focus on grad school, doing PER, and becoming a professor: “I think my main thing about the future is would I be happy doing that forever. And so I think I could see myself being a professor teaching at [university] level, so that’s what had driven me to grad school” (David). In addition, David “wanted to continue to do research, [he] knew that

[he] liked doing research, and [he] liked upper level physics,” whereas teaching high school does not offer David with this range of activities.

As seen in Fig. 5.4 and Fig. 5.6, Ricky and David developed and refined their FPS(es) in a similar way. They both had positive academic experiences in the physics community which significantly contributed to their initial FPS(es) development. They both incorporated social factors into their FPS(es). Finally, they both took a narrowing path to refine their initial FPS(es) with a near-future self of doing grad school. Their near-future selves in grad school enabled them to envision their far-future selves having a job that they are passionate about. We conclude that both Ricky and David incorporated positive past selves into their FPS(es) development and took a narrowing path to progress their future careers.

## **Francisco**

Francisco (he/him) was a senior and double major in math and physics. By the time of the first interview, Francisco was in his last quarter to graduate and determined math as a domain to build a future career in. Within math, Francisco concurrently developed two coexisting FPS(es). One was becoming a mathematician specializing in PDE equations. The other involved teaching math and designing curriculum to improve science education for Latino youth. Math as a career area and two coexisting selves in math were coded as Francisco’ initial FPS(es) by the first interview. We perceived these two FPS(es), a mathematician and an educator, to be independent and might take Francisco significantly different strategies to achieve. Six months later, when Francisco took a follow-up interview, Francisco is now going to grad school in applied math (coded as near-future self) and had ruled out the FPS a teacher because “now [he] realized might not necessarily be the best fit for [him].” Similarly to Ricky and David, Francisco took a narrowing path to refine his initial FPS(es) of becoming a mathematician who will focus on PDEs but not necessarily continuing the path of becoming a teacher (Fig. 5.9). This section presents Francisco’ past selves influencing his initial FPS(es) (Fig. 5.7 and Fig. 5.8) as well as what steps taken by Francisco to rule out the FPS as an educator.

**A FPS as a mathematician** After graduation, Francisco “would like to be a mathematician.” Francisco narrowed this intention to “going for applied math at institutions that have research in partial differential equations (PDE).” The development of a possible self in applied math mainly came from Francisco’s engagement in math and PDEs, forming a strong interest in the field. For example, Francisco wanted to do graduate school with PDE because “by sophomore year, [he] was already solving ODEs and PDEs, so [he] had a lot of experience with that.” Throughout the interview, he constantly mentioned that “[he] knew [always] wanted to pursue math,” “[he] really liked PDE equations for some reason,” and “all the graduate schools that [he’s] looked into [he] had to make sure and double sure that they’re doing research in PDE’s, otherwise [he’s] going to be happy there.” Explaining his own interest in PDE equations, Francisco said “there was something about modeling the world or the universe mathematically that just naturally drew me to applied math” (Francisco). Thus, we argue that past selves of solving PDEs equations in math classes were academic experiences that enhanced Francisco’s strong interest in math, influencing the development of FPS(es) in math.



**Figure 5.7:** *Francisco’s past selves influence the development of a FPS as a mathematician*

Not only interests, experiences in math also fostered Francisco’s self-efficacy in math. When being asked about factors that had been driving his decisions for a PhD, Francisco expressed: “I was always just really good at math, I wasn’t physically, athletically fit, so I just explore the one talent I have and just go with it. Math was the one I was really good at and I ended up loving it” (Francisco). Similarly to David “being somebody who is really good at physics,” Francisco perceived himself to have a talent in math, motivating him to continue to do math and having a career in the field.

In addition, doing a PhD in applied math “might not necessarily be limited to things in

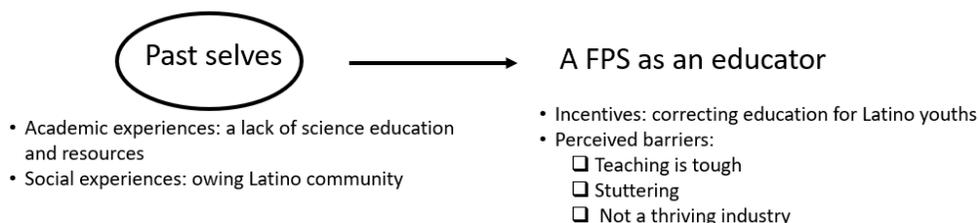
physics. As [he] kept looking into applied math programs, they sometimes pair [students] up with a faculty in another department, one in the math department and then one in physics or engineering. So [he] didn't see this as discontinuing physics." Moreover, becoming a mathematician can also "make an everlasting impact, be remembered like Newton or Einstein. [He] does not know if that would be possible but at least putting in the effort to make an impact like that would be something that [he wants] to do in terms of science and mathematics." These features act as incentives to keep Francisco moving forward to become a mathematician.

In contrast to Ricky, the FPS as a mathematician did not seem to be influenced by past selves of attending conferences or research. Although throughout the interview, Francisco did mention his research experiences and conferences, they did not appear influential to Francisco's FPS(es), they were simply some academic activities that Francisco was involved in as a part of college. For instance, when being asked about participating in conferences, Francisco said that: "I'm a part of SPS, but I don't know, I didn't feel like I fit in there sometimes. SACNAS conferences were in October, I never felt it was a good time for me to go" (Francisco). Regarding research, Francisco "has done three summer research projects. The first two were in physics and the last one was in mathematics. So the first one was looking at the two-point correlation function. The second one studied Type 1 supernovae." Speaking of his second research project in physics, Francisco recalled: "I was happy with my work. The one I felt, I guess, more proud of myself because I actually got some results. I found these distributions of, it measured the magnitude of B-band, so the blue light frequency, sort of how it rises then it peaks at the supernova" (Francisco). The third research "was going to be in partial differential equations but the faculty could not provide valuable research as the state started locking down and university closing." Thus, Francisco ended up doing research in pure math instead of applied math. From this evidence, although Francisco engaged in two physics research projects and was happy with them, Francisco did not once mention a possible self in physics.

To summarize, in contrast to Ricky and David, past selves of doing physics research did not influence Francisco to develop FPS(es) in physics. On the other hands, past selves of

math classes and solving PDEs were academic experiences that fostered Francisco’s strong interest and self-efficacy in PDEs, leading to constructing FPS(es) in math.

**A FPS as an educator** When being asked about what else he considered to do in future career, Francisco responded: “For sure I know I want to be an educator, whether that’s a professor or someone who designs the course or anything like that” (Francisco). A FPS as an educator was “helping teens,” “helping youth,” “providing the next generation with better scientific education that [Francisco] felt like [he] missed out on.” While two FPS(es), a mathematician and an educator, can be relatable from common sense, Francisco did not seem to consider them as one possible self that he will carry on. Rather, they were two separate and independent possible selves: a mathematician solves “PDE equations,” “some centuries old problems,” and an educator focuses on inspiring youth and improving scientific education for teens.



**Figure 5.8:** *Francisco’s past selves influence the development of a FPS as an educator*

We were intrigued to examine the mechanism behind this FPS. We found that this FPS was strongly affected by his dissatisfaction with education in high school from his community. As we examined, Francisco repeated the fact that he did not know about how college worked many times, indicating this as a reason why he really wanted to improve education for youth: “I don’t know, I sort of in high school at least, I felt lost like I didn’t know a whole lot of what you could do with math until probably my junior or sophomore year” (Francisco). Not being provided with enough information almost caused Francisco not to go to college as finance was perceived as an inhibitor. He recalled: “For a long time I didn’t know that a lot of schools give a lot of financial aid. I didn’t even know the grant was a thing until the end of my junior year. So for a long time, money was like the biggest thing that just made me

think I am not going to go to college or anything” (Francisco). For these reasons, lacking science education and resources from childhood was coded as negative academic experiences that motivated Francisco to become an educator to make a change for his community.

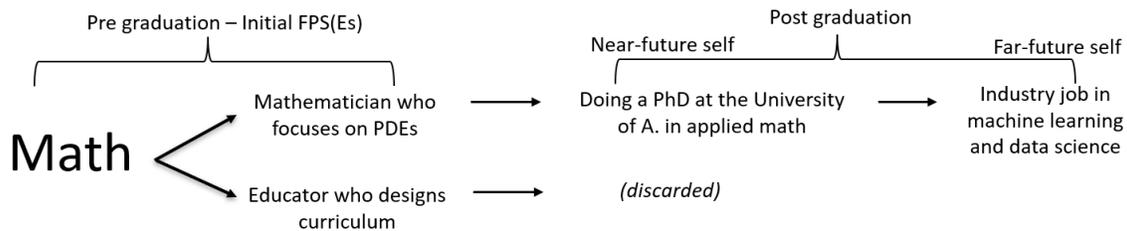
Besides a lack of information resources relating to college, “[he] felt like he didn’t learn enough science in high school so maybe introducing science at a younger age” was important to Francisco as he thought about his future goal. Francisco linked a lack of science education with his social identity: “My town is like 80 % Mexican and the other 20 % is Hispanic, it’s a really homogenous community, it really lacks diversity. Most of us don’t have that much background in science. A lot of us didn’t even know the difference between a chemist and a physicist just because there wasn’t really much distinction between scientists” (Francisco). Not getting a sufficient science education from his community is what “[he] felt like [he] missed out on in education” and that’s what “[he] wants to correct for” young people. Based on Francisco’s perceptions, a lack of guidance, aid, and scientific education from childhood inspired him to become an educator to make a change for his Latino community.

While Francisco associated the possible self in applied math with the term “professional career,” a possible self in education seemed to be more of Francisco’ duty and responsibility for his Latino community rather than a professional. He said: “It is in some part because I came from where I am, I felt like I owe it to somebody. I know people say I don’t have to, but it’s something that always bugged me” (Francisco).

Altogether, past selves of lacking science education were negative academic experiences that inspired Francisco to construct a FPS as an educator. The primary mechanism behind this FPS was to correct science for Latino youths. We conclude that both academic factors (a lack of science education) and social factors (a feeling of owing Latino community) influenced Francisco to become an educator.

**Francisco’s near-future and far-future selves** A follow-up interview was conducted with Francisco after 6 months to update his progress. Currently, Francisco “got into four PhD’s, they were all in mathematics or applied math,” and decided to go to A. University (coded as Francisco’ near-future self). This near-future self continued envisioning far-future

selves: “Machine learning is the one thing that comes to my mind. The other thing is also data science, which goes hand in hand with machine learning” (Francisco) (coded as far-future selves). His thinking towards pursuing FPS(es) in applied math was further strengthened by incentives that a PhD degree in applied math can offer: “Industries are paying you a lot because the future is now heavily involved with computers that they just are paying people and seeking people who have knowledge and good understanding of data analysis, they’re willing to pay you at a higher rate. Money shouldn’t be everything, but you want to live comfortably, and sort of our society’s just built on that, so I cannot really escape that. If money was never an issue, I don’t think I would be worried about a lot of things, but it’s not the way the world works” (Francisco). We conclude that similarly to David and Ricky, Francisco took a narrowing part to refine his initial FPS as a mathematician by accepting a PhD offer. Moreover, we noticed that Francisco became more practical in thinking about jobs. His future job prospects now include not only a passion for math but also a reliable income source to live comfortably, as he said: “Things are just becoming pricey like houses and whatnot, so you know, it’s almost impossible to afford a home at times, and so you need to find a job that pays you extremely well to buy a house if you want a house” (Francisco).



**Figure 5.9:** A narrowing path taken by Francisco to refine and elaborate on his initial FPS(es)

Interestingly, Francisco no longer considered being an educator as his FPS. When the interviewer asked about his plan for being an educator, Francisco “thought [he] could have been an educator but now [he] realized might not necessarily be the best fit for [him].” Some barriers in education and teaching drastically pulled Francisco away from this FPS(es): “There were some kids that I really liked tutoring, but other kids are a lot tougher. I’m patient with them but at the same time, I don’t know if I want to do this which is not the

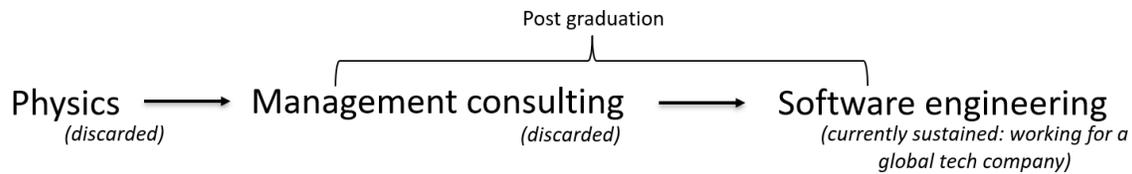
sign of a good educator. I don't want to be a teacher who gives up on kids" (Francisco). Adding to these challenges was Francisco's self-perceived limitations: "I stutter a lot and take odd pauses in between talking, that's not necessarily the image I want to portray or project onto people. The image is a very important thing for educators, you shouldn't judge a book by its cover but if you don't sound confident or act confident, that doesn't sound like it's going to be a good time for the students" (Francisco). Furthermore, he also thought that "[education] is not really a thriving industry in today's world" compared to machine learning or data science. We conclude that these perceived barriers played a role in discarding the self as an educator.

In summary, Francisco was concurrently considering two FPS(es) in math before graduating: a mathematician doing PDEs research and an educator focusing on improving science education for Latino youth. These FPS(es) were impacted by his academic experiences in math classes and PDEs problem-solving, enhancing Francisco's interest and high self-efficacy in math, as well as Francisco's feelings for his Latino community. However, as time passed, Francisco decided to forego the FPS as an educator in order to focus on refining his FPS as a mathematician.

### **5.5.2 A sequenced path of trying different FPS(es) in series**

To highlight that there are different ways of constructing FPS(es), here we present the last case study, Molly (she/her), who took the sequenced path in which she explored different FPS(es) in different career areas in series. This path is in contrast to the narrowing path. Although a variety of FPS(es) are also developed along the narrowing path, they are still within the scope of a career area, and the sequential selves are specialized from the preceding self. In contrast, the sequenced path has passed through various selves in various career areas. Fig. 5.10 describes a series of FPS(es) in different career areas that Molly has gone through. It should be noted that Molly's diagram differs from the previous three case studies for two major reasons. First, her FPS(es) path is fundamentally different because it has taken her through various career areas. Including too many details on the diagram, such as the initial,

near-future, and far-future selves for each career area, may exceed the scope of a presentable diagram. Second, in physics or management consulting, there is no clear evidence of Molly’s initial, near-future, and far-future selves. These two career paths were discarded prior to Molly’s first interview, making it difficult to place a series of past events on a proper time scale. Only in software engineering can we find clear evidence of Molly’s near-future, current, and far-future selves. As a result, rather than detecting initial, near-future, and far-future selves in each career area, this section will be more focused on explaining mechanisms behind a variety of different career areas that Molly has tested out.



**Figure 5.10:** *A sequenced path taken by Molly to try out FPS(es) in different career areas*

Molly (she/her) is an alumna and were triple major in math, physics, and philosophy. By the first interview, Molly had recently graduated for two months. Thinking about her future, Molly “[wants] to become a software engineer and this is relatively a new idea for [her].” As we investigated further, software engineering as a career area for her FPS(es) was not established at first, but rather after FPS(es) in physics and in management consulting did not work out as she had expected. For example, Molly said: “Originally, I was looking into management consulting, and I went through the whole process, I had some interviews. I had a few offers, but nothing I was interested in...I realized that it wasn’t really for me. So then I made the switch to software engineering” (Molly). We conclude that management consulting was a career area that Molly considered for her FPS(es) for a while as evidenced by having interviews and having job offers. However, this career area did not sustain, resulting in Molly a shift to software engineering. We weren’t clear about how Molly constructed her FPS(es) in management consulting in the first place. As we noticed, most of Molly’s past selves mentioned in both interviews were strongly connected to physics, but not management consulting or software engineering. Here we present Molly’s narratives to demonstrate how Molly went through the FPS(es) in physics first before switching to management consulting

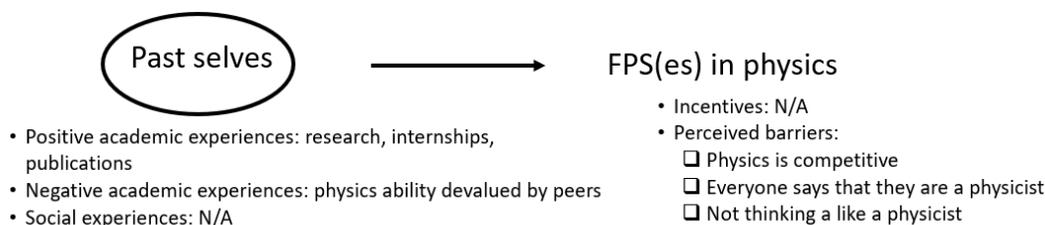
and, eventually, software engineering.

### **Negative past selves sabotaged the FPS(es) in physics**

Although by the time of the first interview, Molly did not mention physics as a career area for her FPS(es). We propose two possibilities. The first is that Molly had never developed a FPS in physics. The second is that Molly had intended to pursue a career in physics but did not sustain. Although we did not obtain explicit narratives from Molly to determine which possibility was correct, the majority of Molly's narratives centered on her previous experiences with physics convinced us that the latter possibility might be the case, whereas software engineering was not developed in the first place during her college time.

For example, Molly admitted that when she first came to college, she didn't think of career as "[she] was just trying to get through. Hearing horror stories of the physics curriculum, [her] only goal was to get through." She got the first class with A which motivated her to continue to do physics: "I really love doing it so I'm going to move forward with it" (Molly). After that, Molly "was on the track to do a PHD program for three years, and did five internships in physics." Her whole experiences of doing physics could have set her up for FPS(es) in physics, as she shared: "I did a research experience for undergraduate opportunity at the University of C. my freshman year and then my sophomore year. I did a little bit of work with Dr. L in the physics department. We did an experiment at Argonne National Lab and I also worked at the Weizmann Institute of Science in Rehovot, which is in Israel. My work at University of C. resulted in co-authoring a paper in Nano Letters, which is a high impact journal. And I gave a few talks, I think I gave 10 total between posters and oral presentations. So I was really into it for a while" (Molly). Given the amount of engagement in physics, from achieving A in class to doing research, having internship, and even a publication on a high impact journal, we were convinced that Molly was seriously exploring and considering physics as her FPS(es) because she "was on the track to do a PhD program" and "was really into it for a while."

Besides her research experiences, Molly also was involved in conferences and student



**Figure 5.11:** *Molly’s past selves in physics*

groups (SACNAS and SPS). In contrast to Ricky, Molly did not see the value of conferences: “I felt like there were other things that I could do with my time. I moved away from that. I also felt like I wasn’t valued for my physics abilities. I was often put on jobs designing a poster or marketing and that didn’t feel good” (Molly). This quote suggests that Molly’s negative academic experiences, i.e., not being recognized and values by peers during conference time, can lower her self-efficacy, thereby sabotaging her FPS(es) in physics.

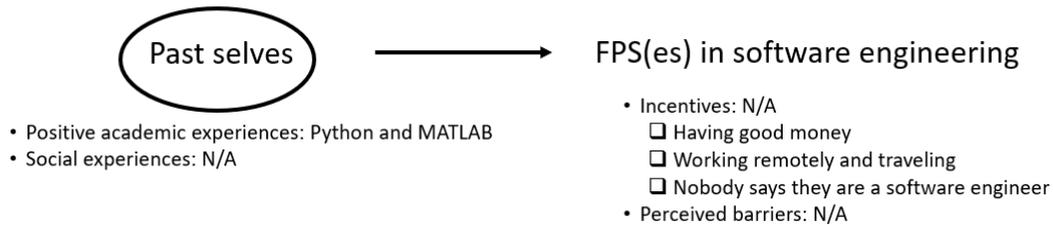
When being asked what happened next after so much research experience in physics, Molly replied: “I don’t know, I think I just really burnt out, and I stopped loving it. I loved patterns in physics, I loved putting together problems, but I don’t know if I think I like a physicist. I don’t know, maybe I will” (Molly). Despite having accomplished a significant amount of work in physics, this quote indicates Molly’s low self-efficacy as not thinking like a physicist. We believe that the low self-efficacy might hamper her intention to continue FPS(es) in physics. Furthermore, Molly perceived that physics is competitive: “I also feel like physics is competitive, it’s hard to focus on the meaning in physics and enjoying physics when everything is so competitive all the time whereas I think in teach, while it’s competitive, it doesn’t seem like anyone goes into software engineering to say that they’re a software engineering. But I think there’s a lot of people who go into physics to say they’re physicists” (Molly). While people in physics claim to be physicists, Molly believed she did not think like a physicist, putting enormous pressure on her to consider becoming a physicist as a FPS. .

From Molly’s narratives, we were convinced that physics used to be a career area in which Molly wanted to build FPS(es), as evidenced by Molly’ active engagement in physics for a while before “[she] just really burnt out.” Interestingly, Molly shared many academic

experiences with Ricky, Francisco, and David, including conference attendance, internships, research experiences, and publications. However, negative academic experiences in which her physics ability was not recognized by others may reduce her self-efficacy, thereby undermining the sustainability of FPS(es) in physics.

### The development of FPS(es) in software engineering

It is noted that after physics was ruled out, Molly moved to consulting management as the next career areas as mentioned earlier: “I was looking at consulting management, and then I started to realize that that wasn’t very interesting to me,” Molly said, despite going through the entire recruitment process and even receiving job offers (Molly).



**Figure 5.12:** *Molly’s past selves influence the development of FPS(es) in software engineering*

After switching to software engineering and determining to build FPS(es) in this career area, Molly began refining her plan by enrolling in a coding bootcamp as a next step (coded as a near-future self in software engineering, obtained in the first interview). While mentioning a lot about her physics experiences, we rarely received narratives from Molly showing the connection between her past selves and her FPS(es) in software engineering, except for some quotes such as “Python was a class that we could take as physics students for an elective, and I was good at and I really enjoyed it. We did MATLAB all through the physics curriculum and so that’s something really helpful” (Molly). This strengthens our arguments that software engineer came as a new career area after her previous FPS(es) in physics and management consulting did not work out, as confirmed by the following quote: “I didn’t realize that I wanted to be a software engineer until after I was into the job search” (Molly).

Molly also listed many incentives in software engineering. For example, when talking

about factors that matter in figuring out a future career, Molly said: “There are a few reasons why I’m interested in software engineering. It’s technical, I get to use my technical skills, it makes a lot of money, which is nice. It has more career flexibility. And then there’s a lot of opportunities to do remote work so if I wanted to travel a lot, I could probably find a remote job, travel while I work or if I decided to have a family, I could part time and be making money, but still be able to have a well-rounded life” (Molly). From these narratives, having good money, working remotely and traveling, and having a well-rounded life are viewed as incentives associated FPS(es) in software engineer. According to the Theory of Possible Selves, the incentives may play an important role in sustaining and guiding Molly’s future behaviors in software engineering.

### **Molly’s current and far-future selves**

Six months later, Molly participated in the follow-up interview. She attended a coding bootcamp, got an interview, and has been working for a global tech company (Molly’s current self). Molly described her new job as “amazing” and also felt proud of what he has been doing: “I love this company so much...We’re learning test driven development, which is something new for me and something that most people don’t learn to do until they’re in a higher position. So I’m learning a lot of things earlier than most people...My peers and supervisor see me moving into a teaching lead position in the next two or three years” (Molly).

Talking about her far future, she seemed to continue what she’s been doing in her current company: “I’ll be going to different companies and coding for them. [The company] is renting out my brain to other companies and those companies tell our team what they want in a product and we build that product for them” (Molly). Surprisingly, Molly brought up the possibility of “going back to grad school probably in the artificial intelligence machine learning area,” and “[she doesn’t] see [herself] doing a PhD in physics necessarily.” However, right now she cannot do grad school because “[she’d] like to save up some money first” and her current job “makes good money,” as she said: “Right now I’m trying to save up as much

money as possible to be able to buy a house when I do a PhD program and may be have a path of income while I'm making a grad student income" (Molly). We are unsure if Molly will ever return to graduate school, given the path she has taken, including many options that she has tried and proposed, ranging from physics to consulting management, software engineering, and now grad school in artificial intelligence machine learning. We just know that for now, Molly is happy with her job as it offers many positive incentives that she is looking for.

In a nutshell, in contrast to Ricky, David, and Francisco, Molly took a sequenced path to try different career areas in series. However, we are unsure about Molly's long-term commitment to software engineering, as she has proposed a desire to do grad school in artificial intelligence and machine learning in her far future.

## 5.6 Limitations

Despite an effort to investigate a wide range of different past selves from four case studies, and two different paths taken by students to refine their initial FPS(es), this study has a few limitations. First, we highly emphasize how multiple case studies as a methodology control some features of the study, as carefully presented in Sec. 5.4 and in Chap. 4. All past selves that have an influence on students' FPS(es) development are active in the working self-concepts of four case studies analyzed in this study; they are not representative of all seniors and recent alumni's past selves. Second, we believe that there are more than just two paths of refining the FPS(es). In reality, ones can even pursue two possible selves in parallel. For example, many faculty in university are involved in both astrophysics and education research. Thus, two paths taken by students in this study do not present all possible paths to refine FPS(es). Finally, we do not have access to students' long-term plans and do not intend to conduct additional longitudinal interviews to check in with students after years in their careers. We did our best to interpret students' long-term futures based on their narratives at the time of the two interviews. In reality, students may develop a completely different self in the distant future, and their new image may influence our findings in an

unexpected way.

## 5.7 Discussion

This chapter explores the last overarching component in supporting undergraduate students to develop professional identity after gradation. The study uses the Theory of Possible Selves to examine students' career development, including understanding the impact of past selves on students' FPS(es) development and the path that students take to refine their FPS(es) as they gain more personal values and experiences. This section discusses the findings of the study, connections with the existing literature on future career development, and further suggestions for instructional design.

**RQ1: How do students bring their past selves to develop future professional possible selves?** The analyses of four case studies' longitudinal interviews (Ricky, David, Francisco, and Molly) reveal a diverse range of past selves incorporated into their future possible selves development. We notice that both academic and sociocultural past selves contribute to FPS(es) development, which is consistent with the theory and literature discussed in Sec. 5.3 about the relationship between academic and social values in career development. Overall, positive academic experiences from courses, conferences, research, and community support can all foster a strong interest and high self-efficacy in the field, influencing the development of FPS(es) in that field (as seen in Ricky, David, and Francisco). In contrast, as seen in Molly, not being intellectually valued and recognized by peers can reduce students' self-efficacy, sequentially deconstructing students' FPS(es) in the field. We conclude that creating a learning environment that can foster students' interests and self-efficacy is critical in supporting students to retain their FPS(es).

These academic factors are well-aligned with previous studies on career development. Particularly, self-efficacy has been a popularly influential factor in students' learning, including occupational considerations.<sup>172;175-177</sup> We observed that both David and Francisco, who perceived as being really good at physics and math, respectively, developed an inten-

tion to have FPS(es) in the field where they had high self-efficacy. In contrast to David and Francisco, Molly had a low self-efficacy in physics, perceiving herself as “not thinking like a physicist,” which may have contributed to her decision to drop FPS(es) in physics. Despite strong support from prior studies indicating a disparity in self-efficacy between men and women in physics, we had little evidence to investigate in depth the correlation between gender and self-efficacy perception.<sup>17;19;34;37</sup> Nevertheless, evidence obtained from students’ narratives in this study confirms the importance of self-efficacy in shaping future careers.

A large body of literature emphasizes the significance of research in shaping disciplinary identity and future career.<sup>7;9;138;188;189</sup> This present study partly agrees with claim due to the diverse effects of research on Ricky, David, Francisco, and Molly. While research allowed Ricky and David to explore their passions, Francisco did not necessarily need a particular research in applied math to realize his passion in PDEs, indicating Francisco’s strong interest from classes can be substantially adequate to construct FPS(es) in applied math. In contrast, despite having researched and had published a paper in physics, Molly did not see FPS(es) of becoming a physicist. Different effects of research on students imply that research alone cannot guarantee the development of students’ identities; rather, research can provide a mechanism for students to examine if they can envisage a long-term commitment to undertaking such research in their distant future.

Molly’s decision to discontinue her FPS(es) in physics suggests that identity development and future careers do not solely lie with positive academic experiences. For instance, Molly had good research, resulting in a publication. However, this positive experience will not be enough to sustain her physics identity, if her recognition and self-efficacy are absent. Thus, a learning environment that can support students’ identities and, consequently, future careers must ensure a variety of factors, including an increase in students’ recognition from peers and self-efficacy.

A supportive community, as mentioned by David, appears to be a contributing factor that influenced him to pursue FPS(es) in physics. Previous study suggests that the interconnectedness of community members is an indicator of fostering sense of belonging.<sup>223</sup> Scholars have also implied the contribution of sense of belonging to students’ learning and,

consequently, translating into students' career choices and intentions in STEM. <sup>102;105;224</sup>

In concert with academic experiences, sociocultural experiences are also incorporated into FPS(es) development. Here we highlight social identity as an important component, <sup>199;210;213;214</sup> but it plays out very differently for Francisco and the rest of case studies. While Ricky, David, and Francisco expressed a desire to help others in the future, Francisco's focus was on his Latino community, whereas Ricky's and David's were depersonalized. The relationships between possible selves and social identity imply that future-oriented activities to support career development should be contextually and strategically designed for different groups of students so that they can match up with their needs and backgrounds.

The congruence between one's personality and perceived future characteristics of careers is consistent with previous studies, highlighting that students should be able to know whether future occupational traits will fit their personality. <sup>170</sup> For example, more than 10% of students in natural and physical sciences perceived their social and professional communication skills are different. <sup>170</sup> This is aligned with David and Francisco, who expressed their traits in relation to their FPS(es). David, for instance, perceived himself to be talking a lot and good at communication to become a teacher, whereas Francisco considered his stuttering to be a barrier to become a good teacher. While previous studies found that students struggle to identify the differences between themselves and traits of future professionals, <sup>170</sup> this study adds that students also can hold negative and misconceived characteristics about the future profession, such as education is not a thriving field, stuttering cannot become a good teacher, and people who go into physics call themselves physicists. The difference between personal traits and characteristics of professionals can be an impediment to pursue a future career. Thus, some interventions throughout undergraduate programs should be designed to provide students with an accurate picture of the characteristics of future careers that students wish to pursue.

**RQ2: What is the nature of future professional possible selves paths during the transition from pre to post graduation?** This study observe two paths that students took to refine their future possible selves. The narrowing path, taken by Ricky, David, and

Francisco, is to refine their initial FPS(es) in a career area into more specialized over time. The sequenced path, taken by Molly, entails trying a series of FPS(es) in different career areas in order until the best self emerges. We believe that these two paths are novel and make a significant contribution to the literature on career development in a higher education setting. Because identity development is a process of exploring and becoming rather than an end point,<sup>170</sup> findings of two paths shed light on such a process of adjustment and refinement for their career intention in order to become who they want to become in their futures.

Although we make no claims about which path is better for pursuing a future career, it is clear that students who take the sequenced path require more resources to help them determine career goals earlier in college. Knowing who they want to become earlier in life can help them develop a better strategy for pursuing their career goals. In Molly's case, for example, "[she] didn't realize [she] wanted to be a software engineer until [she] was in the job search." Her belated realization of her future possible self as a software engineer directed her actions not to "take more coding classes in college." We contend that if Molly had been able to envision her future self in software engineering at a younger age, she would have planned her actions accordingly to take more coding classes and would not have gone through consulting management before determining her FPS(es) in software engineering. Despite her current impression and enthusiasm for her current job in the global technology company, Molly expressed an interest in returning to graduate school for machine learning and artificial intelligence at the end of the interview. Molly's current self appears to be preparing a strong financial foundation for her future self in graduate school, rather than a long-term commitment with her self in software engineering. An alternative interpretation of Molly's path is that she is still trying to figure out who she wants to be. Nonetheless, Molly, who chose a sequential path, needs more resources for her professional identity exploration, as she stated: "Many physics don't go into physics, they go to finance or software engineering. So it's, I think, more resources would be great for this" (Molly).

Tim Clydesdale, an author of the book "The purposeful graduate: Why colleges must talk to students about vocation,"<sup>225</sup> states that the good news for higher education is "when colleges and universities meaningfully engage their organisational histories to launch sus-

tained conversations with students about questions of purpose, and the result is a rise in overall campus engagement and recalibration of postcollege trajectories that set graduates on journeys of significance and impact” (preface, p.xvii). This quote and our findings have reflected a need for more vocational programs and career-related resources in undergraduate programs, so that students can understand the relevance and significance of college in relation to their future success. Because future possibilities selves are continually developed and changed, vocational programs, therefore, should not be simply brochures with information and minimum versus preferred qualifications by the time that students graduate and need a job, but should instead include significant involvements from adults as negotiation partners, such as parents, mentors, experts, administrators, etc., who will have an ongoing and active involvement throughout students’ professional identity exploration.<sup>207;226</sup>

# Chapter 6

## Conclusion and future work

This thesis presents three major studies corresponding to three overarching components of the undergraduate programs in order to support students to develop professional identity: equitable interactions in advanced physics labs; developing a sense of belonging in departmental communities; and envisioning future possible selves after graduation. These studies combined provide a holistic and reflective picture of what students need, as well as an overall climate in STEM, particularly in physics as a community and a department. This chapter summarizes some key findings from the three studies, proposes some takeaways to the ongoing curriculum, and opens the future work to continue supporting students' professional identity development.

Beginning in physics classrooms, this thesis confirms one of the major issues in physics education: inequity still exists. The dynamics in which one student is in charge of directing the group's activities are still visible, reducing the likelihood of group members fully engaging in the physics experiment. The disparity in accessing experimental equipment and mutual discussions among members in a group raises threatening questions about who can do and who can belong to physics. Although answering these questions requires more evident data to further investigate the relationship between gender, prior academic background, and equity, findings from this study still put weight on physics classroom instructors to pay more attention to equipment accessibility and ongoing discussions in a group to improve

equitable learning for all students. Based on the findings of this work, some instructional suggestions have been highlighted, such as implementing a classroom policy of sharing equipment, attending students' positionings, evaluating students' accessibility to the experiment in relation to their positionings, and grouping students accordingly to ensure students with low positionings are placed in groups with equitable access to the experiment. There will never be a perfect solution to address inequity or ensure equity in physics classrooms, but we believe that if more attention is paid and actions are taken by ongoing instructions, equity is potentially practicable and achievable. Future work continues to collect both qualitative and quantitative data from students in order better investigate the correlation between students' access to the experiment and their personal variables such as gender, socioeconomic status, prior physics background, and personality.

Going beyond physics classrooms should be the attention to students' sense of belonging (SB) across their departments. A variety of departmental features are identified in this thesis, emphasizing some features that either support or hamper students' SB. Some common features that are highly valued by students include the interactive and collaborative group work inside and outside of the classrooms, research opportunities for undergraduate students, departmental encouragement to participate in extracurricular activities, and faculty support for career development. Opposing to these supportive features can diminish students' SB, such as fewer collaborations and fewer interactions between faculty and students outside of the classroom. We find these features straightforwardly applicable to the ongoing undergraduate curriculum, in which departments should incorporate more interactive engagement into teaching pedagogy and encourage group work to give students a sense of community. Furthermore, building structures appear to be a physical barrier to developing meaningful interactions with other department members. Despite the fact that we documented building structures as a students' concern, changes in building structures or locations can go beyond what curriculum administrators can adjust. As a result, we propose concentrating on more likely changes, such as collaborative pedagogy or research accessibility for students.

After graduation, students continue their journey on career development. This thesis finds and also confirms the association between students' academic factors and their

future-oriented thinking. More specifically, positive experiences from courses, research, and conferences can enhance students' interest and self-efficacy in a discipline/field, resulting in constructing a future possible self in the field. In contrast, not being valued and recognized by peers may sabotage students' self-image in the field. The strong influence of these factors, however, is no longer surprising because a large body of research has continuously highlighted and pushed the curriculum developers to incorporate these factors throughout undergraduate programs. What is more significant in this study is, perhaps, students ponder the future impact that they can bring to the society, such as an intimate impact on patients, an impact on students to learn better, or even an impact on minority youths to have better education system. The incorporation of societal impact into future careers indicates an urgent need for future-oriented programs that provide students with an informative picture of what each career can offer and contribute to future society in relation to students' personal goals and values. Furthermore, while there is no need for an accurate path to build a future career, two paths taken by students, namely narrowing path and sequenced path, suggest that future work should design more future-oriented programs and resources to help students determine their possible selves early so that students can have a better strategy to implement their career goals.

Although this thesis presents the three overcharging components as three separate projects, we contend that these three components are strongly correlated. For example, we believe that a departmental sense of belonging necessarily begins with a sense of belonging within a classroom, which can be fostered by ensuring equitable interactions and learning for students. Senses of belonging, both inside classrooms and across departments, have a substantial impact on students' persistence in the field and play critical key roles as positive academic experiences, which in turns significantly translate into students' future career possible selves. The connection between equity in a physics classroom, departmental sense of belonging, and future possible selves development suggests that the on-going curriculum should pay parallel and concurrent attention to all these three overcharging components in order to better support the development of students' identity throughout their undergraduate programs and after graduation.

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# Appendix A

## Interview protocol

### A.1 Design problem

Develop curricular resources for DePaul physics students to help them explore their sense of purpose and career planning.

### A.2 Research questions

**What are the needs and motivations of DePaul physics students around issues of career planning and exploring one's sense of purpose?**

1. What factors influence students' thinking about and decision making regarding career?
  - Knowing the factors that influence them helps us in the design phase to attend to their current needs and helps them attend to their own needs which helps their future planning be better.
2. How do they conceptualize the idea of purpose and how do they generate their ideas about their own purpose?
3. What resources do they currently use, how do they use them, and what (perceived) needs do they have to help them think about career planning and exploring purpose?

4. How do needs (or perceptions of needs) change over time (lower-division, upper-division, alumni)?
    - If ideas of purpose or perception of need have changed over time, what experiences do they cite as being influential in that change?
  5. What are their perceptions of what is currently happening at DePaul vs. what they need and want?
- 

- Try to establish connection with the interviewee, and pay attention to their emotional state.
  - Don't ask more than one question at once.
  - Be more open-ended in questions. Stop, then see what they say - can follow up with, Is it more like X or like Y? if needed
  - Don't be afraid to ask something again if we don't feel like they understood the question properly; try re-framing.
- 

## A.3 Set-up and introduction

[Gallery view. Open up Chat window. Make sure it's visible, and select Private chat first.]

“Hi, I'm **NAME**. Thanks for taking the time to talk to us today. **NOTE TAKER NAME** is primarily going to be taking notes, and may chime in at the end with some questions if we have time.

Just to refresh your memory, this study is looking to understand the wants and needs of DePaul physics students around issues of career planning and exploring one's sense of purpose. The goal of this project is to create better resources throughout the DePaul physics curriculum that are specifically designed to meet the needs of our students. Also, just a

reminder that I'm not affiliated with DePaul, but am collaborating with Dr. K and she is the only person affiliated with DePaul who will have access to this interview.

Did you get a chance to look at the information sheet attached in a recent email? Did you have any questions? Do you agree to participate in this research?

And just a reminder, I do have a variety of questions today, but just want to have a conversation to learn about you and your experiences around career planning.

I also wanted to confirm that you're ok with me recording this interview? [Make sure in Gallery view; Check that recording has started.]

While we are recording, do you agree to participate in this research study? In order to protect your identity, we will use a pseudonym to refer to you during the study. Do you have a name that you would like us to use or would you prefer that we pick one? What pronouns would you like us to use for you?

Great, thank you again!"

## A.4 Interview questions

Below are a set of questions that may be asked during interviews. Not all questions will be asked of all participants. In addition, the interviewer may ask follow-up questions based on participant responses.

Questions that are specific to a particular population are:

- Purple: current students only
- Blue: alumni only

### A.4.1 Background

As a part of trying to understand your experiences, it would be helpful to get to know a little about your background.

- Where are you in the physics program?

- What physics classes have you already taken?
- How long has it been since you left DePaul?
  - What have done since leaving DePaul?
- Do you currently have a job or jobs?
  - Do you consider your current job a career?

### A.4.2 Career planning

Think back to when you were first deciding where to go to college or your first year at DePaul.

- Why did you decide to major in physics?
  - What **is/was** your concentration and how did you decide on this?
  - **Do/Did** you have any double major(s) or minor(s) and how did you decide?
- Why did you decide to attend DePaul?
- At that time, were you thinking about careers in physics?
  - If yes, which ones did you know about?
  - How did you learn about those careers?
  - How important were career possibilities for you in choosing physics?
- Thinking about where you are now, how has your thinking about careers changed?  
**How did your thinking change over your time at DePaul and where are you now?**
  - Are there any particular experiences that stand out to you as helping to change your perspective?

- \* Some people say they had an advisor or they took a class or had a research or study experience, were any of these important?
- If they say it hasn't changed: it is unusual for this not to change, can you say a little about you think it hasn't?

### A.4.3 Factors that influence

I want to talk about what are the things that influence your career and what is important to you as you are planning your career.

- As you are making decisions about your **current/future** career, what are the kinds of things that you are thinking about or trying to balance among?
  - Connection to physics degree
  - Family (current, future, partner/children)
  - Money
  - Personal fulfillment
    - \* What sustains you?
    - \* What brings you joy?
    - \* How do you want to be remembered? In your workplace? In your life?
  - Doing good
    - \* What problems do you want to solve in your life or in your career?
  - Location (specific or access to resources/amenities)
    - \* Pay attention to DACA/international if they bring this up
    - \* When you think about doing that, do you think about being in a particular location?
    - \* When you think about settling down in X, what do you think about the shape of your career?

#### A.4.4 Exploring a sense of purpose

As a part of DePaul's mission, one of the goals is for students to not only strive for academic and career success, but also live a life grounded in meaning and purpose. So, let's expand our conversation to thinking about your sense of purpose or meaning in life.

- How do you think about your sense of purpose or meaning in life?
- How, if at all, do you think your sense of purpose or meaning in your life is or might be connected to your career?
  - What is it?
  - Where does this thinking come from? Specific experiences, family, etc.
- Who do/did you talk to about things like your purpose in life or your broader life goals?
- What has been helpful for you in thinking about your purpose or broader life goals? What hasn't helped?
  - What would be helpful for you in the future?

#### A.4.5 Support and resources at DePaul

I want to talk about some of the support and resources at DePaul. And just a reminder that I'm not affiliated with DePaul.

- How did/does DePaul prepare you for thinking about your sense of purpose?
- How, if at all, have your physics classes helped you in exploring your purpose? What about your career goals?
  - Which classes?
  - Can you talk about specific experiences? Events, activities, topics, etc.
  - What about non-physics classes?

- Who at DePaul do you talk to about career ideas or future plans?
  - Academic advisor
  - Other students (peers, seniors, clubs - SACNAS, SPS, SWiP, etc.)
  - Faculty (physics, non-physics)
  - Peer Mentors (CQM, STARS program, student success coaches)
  - Career Center
  - Internship/REU advisor
  - Student support services (1st-year academic success, identity-specific cultural/resource centers, PATHS program, Men of Color Initiative, etc.)
    - \* What kinds of things have they done that you have found helpful? unhelpful?
    - \* **What would be helpful for you in the future?**
- Are there any events/programs at DePaul that you wanted to participate in, but didn't and why?
- **What are the 1 or 2 things at DePaul that you would recommend for anyone starting out in the physics program?**

## A.5 Wrap-up and closing

- *At 50 min:* I'm mindful of your time; do you need to go right at XX time?
- Before we close, is there anything you'd like to add, or anything we should have asked you about, but didn't?
- Are there any questions that you have for us?

*Personalized closing about how what they are doing is really cool and interesting, and potentially how what they've shared with us is really going to be helpful for us. "Thank you so much for your time! This was very useful and we really appreciate it."*

If they have questions about the study:

We hope to use the information we are getting from these interviews to design activities around career planning and sense of purpose that will meet the specific needs that our students have. During winter and spring quarter, we plan to use what we learn from these interviews to work with faculty to build and adapt activities for the physics program that fit within specific classes, but also build over the course of the program. Our plan is to start testing activities next fall with current students and revise them over the next academic year.

If they ask about “personas” (it’s in the title of the study):

After we analyze and synthesize the interviews, we will create a set of fictional characters that reflect the themes and variations that we see in the data. These personas are not connected with any specific people, but are true to the experiences of those we interview. This allows us to focus our design on a small set of realistic students who represent the wants and needs of real DePaul physics students, without being connected to any specific individual student.

# Appendix B

## Francisco's interview transcript:

### Round 1

DePaul-Francisco-Transcript

Ellie: So you can tell that we're recording because there's the thing at the top of your screen with the blinking red dot.

Francisco: Actually, I have the participant's name on the right side, so I see where your names are.

Ellie: Oh, sorry. I'll need to move that. Yeah. Okay. Francisco: Oh, okay. No, now I see it.

Ellie: Yeah, I forget that I'm flipped on your screen. So it's on this side for me, but it would be that side for you. And while we are recording, do you agree to participate in this research study?

Francisco: Yes.

Ellie: 0:00:38.0 And in order to protect your identity, we're going to use a pseudonym to refer to you during the study. Do you have a name that you'd like us to use?

Francisco: Francisco.

Ellie: All right. Will do. And what pronouns would you like us to use for you?

Francisco: He, him, his.

Ellie: Cool. All right. Will do. Do you have questions before we get started?

Francisco: No.

Ellie: All right. Can you talk about where you are in your physics program?

Francisco: 0:01:09.0 So this is actually my last quarter, so I will be graduating right after this. So basically, I'm done with my physics program. Right now I'm just taking an independent study just so I have something to do before I graduate. Also, with everything that's going on right now, I figured it probably won't be the worst thing to do right now.

Ellie: What are you doing for your independent study?

Francisco: PDE's. So I'm studying the KdV equation, which is a non-linear partial differential equation. It shows up a lot with water waves, I think. I know it doesn't sound professional for me to say I think, but I've mostly been trying to find a solution to it and haven't found a whole lot of physical applications just yet.

Ellie: 0:02:19.8 That sounds really cool. What drew you to doing this as an independent study? I think part of it was my physics background. So by my sophomore year, I was already solving ODE's and PDE's so I had a lot of experience with that and I think it's sort of what I would want to study in graduate school. So I'm going for applied math. Right now I'm applying so I'm looking at institutions that have research in partial differential equations. So I kind of wanted to sort of to get familiar with the study of PDE's and its... Because I've solved things like the Laplace equation, the wave equation, what was the other one? The heat equation. They're relatively simple if that makes any sense. Although, they're not that simple. Simple in the terms of PDE's.

Ellie: I mean, they're nice looking PDE's, I'll give you that.

Francisco: 0:03:39.9 Yeah, so they're simple in terms of PDE's, but simple is not probably the best word to describe that. So yeah, that's sort of... So I'm studying the KdV equation since it's the first non-linear PDE that I actually had to examine. We found a simple solution for it, but there is an entire family and sort of the one weird thing about, as I kept researching, on this PDE's that if they're non-linear there could be infinitely many families, not infinitely many families, infinitely many possible solutions even if you have initial conditions. So there was that.

Ellie: Which is exciting, I mean, to think about that as a class or to think about families of solutions. Yeah. Are you also a math major?

Francisco: 0:04:47.1 Yeah. No, good ahead.

Ellie: Oh, I was going to say, how did you decide to do physics and math together?

Francisco: Originally, I knew I always wanted to pursue math, but physics I think just because I liked all the weird equations that showed up. So that's sort of what drew me to it. I remember in high school we were talking about. . . I think we were talking about, yeah, electromagnetism, sort of how Coulomb's law is very similar to Newton's law of gravity or inaudible 0:05:28.9 gravity. So like kind of searched up electromagnetism and I got some weird, at the time I didn't know what a divergence or what the curl was, so I'm just seeing like all these triangles and stuff and I'm like, "what is all of this?" And yeah, then I spent the next four years after that just learning all that.

Ellie: Cool. And then do you have a concentration as well? Are you. . .

Francisco: 0:06:01.8 For math it's pure math and for physics it's standard physics, so it's sort of a little bit of everything, EM, classical mechanics, quantum. I know there were some astrophysics classes, but sadly, I never took any. But yeah, so far this is mostly sort of all the stuff I took. I also took a class on experimental physics, so just kind of getting used to like doing experiments, understanding how to calculate error and uncertainty, and then the last experiment was pair production, which I thought was kind of cool.

Ellie: What was cool about it?

Francisco: 0:06:53.2 Just creating particles. I mean, I didn't really create them, but like if I remember it correctly, sort of you could have a proton, not a proton, sorry, a positron and an electron appear, and the weird thing was. . . I mean, it's always known, since like day one at least, when we were taught physics, but things were conserved like the energy of the inaudible 0:07:25.2 and what the photon becoming the positron and the electron, but then there was also that fact that the linear momentum was conserved when that happened, and then charge was also conserved, which shouldn't be a surprise, but I don't know why that tripped me. I mean, the experiment itself didn't look anything quite fancy, it was just like a little. . . I forgot what element it was. I think it might have been Cesium. And then we

had something shooting photons and I don't remember the name of the device. And yeah, we were just detecting particles that were hitting at opposite ends. So we would have one detector this way and then one exactly 180 degrees and it would read if two things hit it simultaneously then we would think it was sort of both a positron and electron being emitted simultaneously. I don't know, I just found that really weird. I mean, I've read about it, but it's just weird just knowing it's sort inaudible 0:08:40.4 thin air. I don't know why I had an accent there for one minute. I don't know why they appeared out of thin air, but... Well, I do know, but it felt like that. Oh, sorry.

Ellie: 0:08:54.2 Cool. All right. Can we like... Let's think about when you were first deciding where to go to college. Why DePaul?

Francisco: Math is actually what drew me there. So a lot of my math teachers went there, so I thought, "well, they all seem very educated, so why not just apply there?" So...

Ellie: Are you from Chicago?

Francisco: Huh?

Ellie: Are you from Chicago? Francisco: Cicero, so it's right near Chicago. You know, the southwest of Chicago.

Ellie: Cool. And did you look anywhere else as well?

Francisco: UIC, which is a school nearby. University of Illinois Chicago. University of Chicago. Most of the schools were mainly around Chicago just because my mom had like some health problems that year, so I kind of wanted to stay near home.

Ellie: 0:10:12.0 Yeah, I understand. Okay. And do you still want to stay in Chicago?

Francisco: I would like to, but no, I don't think it's necessary. I think... Because I also want to go to Colorado to study over there, applied math over there. So it'd be nice because I could save money, but no inaudible 0:10:38.0

Ellie: Fair. Fair. Okay. So it sounds like you're pretty settled on like which applied math programs to look at or are you still looking at a bunch?

Francisco: I've selected some, but I'm still looking for more just because I figure the more schools I apply to probably the better chance I like actually start next year. This year's kind of been hectic so... I mean, there's positives and negatives for this year about applying.

But I know some schools might cut the number of new admitted students this year.

Ellie: Yeah.

Francisco: Go ahead.

Ellie: 0:11:22.3 Oh, I was going to say, if this is your last quarter, what are you planning to do between the end of this quarter and the beginning of fall term?

Francisco: So I've kind of been looking at labs, so Argonne and Fermi to see if I could get a position there at least until the fall semester starts. And I also have a job as a tutor so in case that doesn't work out, I always have that other job.

Ellie: Cool. So it sounds like when you were applying to undergrads, you were mostly thinking about math stuff?

Francisco: Right.

Ellie: How did you get started in physics? Francisco: 0:12:16.9 Sort of the month after I graduated high school, I had a time between then and orientation to think, for once. I didn't have like AP tests or anything to worry about. So I just had nothing to do. And also, I never really stopped learning physics, I would still learn, because I took AP physics my junior year of high school and I still learned a little bit here and there after I took that course. And I had a lot of unexplained questions. So maybe to make a long story short, I took calculus my senior year of high school, but I took physics my junior year so then I sort of started making connections and like, "oh, so this is how we get the equation of freefalling object and stuff like that." So sort of when I started making that connection, I'm like, "maybe I could just see other connections being made." So it sort drew me into it. And then there was also like the line integrals and weird math I saw, so I'm like, "maybe if I go into physics, I might use a lot of this math," and I did. So it was mostly, I guess, the applications that really drew me to physics.

Ellie: The applications of math?

Francisco: Yeah.

Ellie: 0:13:53.6 Yeah. Okay. And thinking about where you are now versus where you were when you first got to DePaul, how did your thinking change about what to do after graduation?

Francisco: So when I first came, I thought I was going to do graduate school in pure math, but then I kind of got really interested in physics, especially astrophysics. So I thought maybe I want to do astrophysics, but then I kind of realized... Because the things that were like really interest me were general relativity and sort of all the, I guess, fields in physics that were really heavily based on math. So I thought maybe applied math might be a little bit more general, so I guess it could apply to more things. But at the same time, I had narrowed down my focus to like it being mathematical than just, I guess, like observations and sort of reading the data and stuff like that. So I feel like I didn't answer your question, so I'll answer your question. I went from wanting to pursue PhD in pure math to astrophysics and then to applied math.

Ellie: 0:15:23.7 Okay. Okay. And are there any particular experiences that stand out to you as helping change this perspective?

Francisco: I really can't think of any. I think was just probably something that sort of happened throughout the four years sort of.

Ellie: When did, hmm?

Francisco: Go ahead.

Ellie: When did you settle into applied math?

Francisco: I want to say November of last year.

Ellie: What happened in November?

Francisco: 0:16:12.5 Well, there were applications for graduate school, and I was sort of thinking like, what is that I really like? So I kind of just took a couple of weeks to stop and wonder about it and what is that of all the research experience I've had and all the classes I've taken and all the things about physics and math that I liked? And I just kind of thought maybe applied math was my thing and so I sort of just started looking into what they do in applied math and I saw that it's a lot of PDE's and... Well, there's also like algebra stuff so like groups and algebraic topology, but I think what, I don't know, I just really liked PDE's for some reason. I know it said it like a hundred times already, but yeah, I think there was something about modeling the world or the universe mathematically that just naturally drew me to applied math and I felt like that might be the best course because

I might not necessarily be limited to things in physics. I could also do it, say, in chemistry, biology, maybe even some social sciences, although I'm not too familiar with that. 0:17:46.9 And then also, as I kept looking into applied math programs, they sometimes pair you up with a faculty in another department. So I know the University of Michigan, they would pair you up with a, they would give you two advisors, one in the math department and then one, say, in physics or engineering. So I didn't see this as like discontinuing physics, but maybe just taking a more mathematical approach to it than I initially thought or that I didn't know of before. So I think it was that last part where I could have two advisors that I think sort of sealed the deal for me.

Ellie: Cool. And as you're thinking about where to go to graduate school or why you want to go to graduate school, what are the kinds of things that you're thinking about or what are sort of the ideas or things that are guiding your decisions?

Francisco: 0:19:00.9 So a big one is actually, since most math programs seem to like give their students either a teaching position or some sort of fellowship, thankfully financial aid isn't a big concern for me. So I guess what's really driving me is more the number of students they admit along with the research that's being done. So all the schools I've looked into I had to make sure and double sure that they're doing research in PDE's, otherwise I don't think I'm going to be happy there. I guess another thing is also I'm sort of looking at their physics department as well, just because I think it'd be nice to... Because I know a lot of the course requirements sometimes lets you take courses in other departments. So maybe I would take a couple in physics just because I think... I don't know, I always wanted to learn differential geometry and general relativity so, but both of those concepts are really hard so that's sort of what I'm hoping to get from. So something that includes general relativity. Even if I don't ever do research in it, I think it'd be a nice thing for me to learn. Maybe make it a hobby if I graduate from grad school.

Ellie: 0:20:54.0 Gee, I've got to say, doing GR is kind of an atypical hobby.

Francisco: It is, but it just like, I don't know, there was something weird that just attracted me to it. I think it was understanding space as like curvature of spacetime, which I still don't know what that means when I say it. So I think that's sort of just something

that I've always wanted to learn.

Ellie: Some people when they're trying to sort of balance among what they want to do are also thinking about like how connected is it or not to their physics degree, or the work that they think they'll be doing, is it personally fulfilling and in what way. But other people also think about like where is this located and what are sort of their geographic considerations that matter to them or do they want to do good in the world.

Francisco: 0:22:05.4 Yeah, I see what you mean now. I guess the best way to say this is I think I just sort of. . . Well, work is work, regardless. So sometimes you'll just be tired and stressed out, but I don't know, I think I would like to be a mathematician. I think that's something that even though I get frustrated with homework and stuff, it's fulfilling for me. So I think some large part of it is probably personal satisfaction from the work. So I guess in terms of physics, I don't know, I always thought that was. . . I always found it really weird that things could sometimes come out neatly in equations or at least approximated neatly, such as like Coulomb's law and stuff like that. That expression, although I'm not sure how accurate it is by modern standards now, I'd say its approximation's pretty nice, I guess. I don't know if nice is the right word for that, but it's very. . . Like, it doesn't seem really confusing, like you don't see like a thousand terms or things to like the hundredth power or thousandth power. 0:24:10.4 So there is stuff like that, I think. I think, I don't know, I just like making those connections and, yeah, I just find it sort of fulfilling when I actually. . . I guess, even if it's a homework assignment, like trying to derive sort of equations of motion, I find that kind of. . . Bless you.

Ellie: Thank you.

Francisco: Satisfactory, just because I sort of know where it comes from. I mean, I don't know, does that sound weird at all?

Ellie: It sounds really cool. Do you. . . You mentioned that you were looking in Chicago because you wanted to stay close to your mom. Is staying close to family important to you still?

Francisco: 0:25:11.9 Yeah, but I guess that over the last four years I've thought maybe, I mean, I realized that because I went through some personal issues sophomore year and school

was pretty lenient with that. So I had to leave for like about a week, but the department and the school... I'm sorry, what was it called? And the deans were really understanding, so I think if anything were to happen with family maybe, at least I'm hoping to, they'll be very understanding if I need to take a leave of absence.

Ellie: Well, and I hope nothing happens.

Francisco: I hope so too, but life's always a little unexpected. I mean, this year's probably the best example of that.

Ellie: Yeah, yeah. So you're planning to get this PhD in applied math and then what?

Francisco: 0:26:20.1 For sure I know I want to be an educator, whether that's a professor or someone who, say, I don't know, designs the courses or anything like that, which I guess are also professors, or the curriculum. I think that's something I know I want to do, just because I feel... I don't know, I sort of in high school at least, I felt lost like I didn't know a whole lot of what you could do with math until probably my junior or sophomore year. So I think maybe also helping teens, I think, is probably a big influence too. I think part of it is just you just don't know. You just turn 18, you think you're an adult and then now you have all these decisions to make. Should I go to college? Which one should I go to? Should I take out a loan or should I wait for a year and work? It's always so... I don't know why it feels like such a big pressure when you turn 18 because just a day ago you were 17, but now it's like the world feels heavier or more in your face. 0:27:56.7 And I think part of that is just that sort of when you learn about college and stuff like that, you learn junior year and then you're worried about the SAT's or ACT's and then you start looking senior year, but then you also have classes and sometimes you have clubs and sports. So, I don't know, I think probably learning about it earlier might be a better idea.

Ellie: What do you mean by that?

Francisco: I guess sort of learning how to select what schools you want, learning what you need to have under your belt. So for a long time I didn't know that a lot of schools give you a lot of financial aid. I didn't even know the Pell grant was a thing until the end of my junior year. So for a long time, money was like the biggest thing that just made me say I don't think I'm going to go to college or anything. And hopefully that's not the case

anymore, but still I think there's a lot of questions people have about college. 0:29:14.4 And then what to major in was also another thing. Like, I didn't know... I guess part of it was I didn't know what to do with math. So I thought maybe, if anything, I could major in physics and maybe that would open more doors of possibility to me. One because I think it's very useful and two, because I find it very, it's something I enjoy. So yeah, I mean, I think that's something I wish I had learned about before starting college because I sort of felt like I had to learn it all, you know, before December when all applications are due, and all essays are due. So I think I would have enjoyed that aid or guidance.

Ellie: Yeah. So part of DePaul's mission is one of the goals is for students to strive for academic and career success, but another part of it is for students to live a life grounded in meaning and purpose. So let's start talking about that. How do you think about exploring your sense of purpose?

Francisco: 0:30:47.5 I mean, I guess a lot of it has to help with youth. I have a sister right now that's just started high school and sort of I've been explaining to her things that she didn't, I guess, like things that I knew I didn't know when I was her age about college and careers. So like I also had to tell her that if you major in something STEM related and pursue a PhD in it, usually, not always, but usually they offer you some type of stipend to live off of, so she thought that was kind of cool. I didn't learn that until my freshman year of university, so I'm like oh.

Ellie: I mean, I didn't know about that until I was a senior in college and trying to figure out what to do next. And one of my profs told me, "well, if you go to grad school in physics, you'll have a stipend, and your tuition will be paid." And I was like, "what?".

Francisco: 0:31:58.2 Yeah, no. I mean, luckily, I knew that beforehand, but still, I think a lot of people are very unsure about that too. I don't know, I think I want to get... I feel like I didn't learn enough science in high school, so I guess part of it is also maybe introducing science at a younger age, especially because my town's like 80 % Mexican and the other 20 % is Hispanic, but other nationalities so it's really homogenous community, it really lacks diversity. But sort of everybody, like most of us don't have that much background in science. A lot of us didn't even know sort of, at least some of us didn't even know the difference

between a chemist and a physicist just because there wasn't really much distinction between scientists. It was either biology or the physical sciences. And I think that's something I felt like I missed out on in education. I sort of felt like I probably want to correct for.

Ellie: 0:33:20.7 And so how does this sense that you missed out and you want to correct for it, how does that relate to your sense of purpose?

Francisco: Provide the next generation with better scientific education that I felt like I missed out on. Not something too crazy where like, you know, it's like only college kids learn. Like, nothing calculus based or in physics anything really math intensive because then that would just make people hate it more. Maybe some would like it, but most people I know don't like math that much. But yeah, I think stuff like that, sort of understanding. . . I don't know, I just feel like that's sort of. . . It is in some part because I came from where I am, I felt like I owe it to somebody. I know people say I don't have to, but it's something that always bugged me too like, some people make it, and some people don't, and I just feel like sometimes people weren't given enough preparation when they started high school just because either your school didn't really teach you enough about science so that you knew what to take in high school or how to prepare yourself in high school to get ready to college. 0:35:02.7 I don't know, it just all. . . Because once people start high school it seems like you're already just starting to get ready for college and, you know, it's kind of hard to get ready for college when you don't even know what you're supposed to know in high school. So, I mean, I guess education is probably, education of youth, is also something I'm really concerned about. You know, I have siblings, I have cousins that are like nine and 10 years old, I have one cousin that's like two years old. So they have a long way ahead until they start college and I wonder if there's anything I could do for them to help them succeed better than I did in school.

Ellie: And how did DePaul help you sort of think about developing this as a sense of purpose?

Francisco: 0:36:03.0 I think part of it was with Dr. Pando, he would always mention like opportunities for us, like research opportunities. So in March, there's a day called research day where everybody would come, and the faculty would present like any research they had

been doing. And there's usually research where they're able to get students on board and on a team to work with them. So I think that's probably one of the things that I thought about maybe introducing kids, teens and even adult students who start college later in life, anybody really, sort of what is it that you can do with what you studied or if you want to study this, these are things we do, and we'll show you like some of the ropes and stuff like that. So I think that's sort of what I thought about when I was wondering how to prepare better in high school.

Ellie: 0:37:39.5 And has anything in your physics classes specifically, I mean, there's research day, which is sort of classes, but not really, class adjacent. Ah yes, it's departmental stuff, but it's not classes. Was there stuff in your physics classes that helped you think about exploring your sense of purpose or your career goals?

Francisco: I mean, I'm probably going to have to say no.

Ellie: Okay.

Francisco: I hope Dr. K doesn't get mad at me.

Ellie: That's totally fine.

Francisco: But I mean, career wise, I've always wanted to, and this probably near to impossible, I've always wanted to solve a Clay Math, one of those Millennium problems. I think it started it off as eight, but there's seven left now. They're these really hard math problems that are thought to fundamentally change how we understand mathematics, but the thing is that they're so difficult that nobody's found a solution for them yet. So I always wanted to do one of those. So yeah, I've always been, I guess that's probably, I try not to say it's my purpose in life because if I don't ever solve one then I don't want to feel depressed about it.

Ellie: 0:39:19.8 Well, your purpose is to work on or make progress towards?

Francisco: Yeah, I guess that'd be the best way to say it. Maybe find a part of a solution and not the entire solution. I guess career wise, I just want to make an everlasting impact, but that's really maybe dreaming too big. I mean, it'd be nice, you know, be remembered like Newton or Einstein. I don't know if that would be possible with me, but yeah, I think at least putting in the effort to make an impact like that would be something that I want

to do in terms of science and mathematics too, actually. Yeah, and I think that's really, in terms of professional careers, I think that's something I want to do. I mean, there's also being a professor, but I think that's what I want to do more in the research aspect, figure out I guess some centuries old problem and try to solve it. Although it's centuries old, I think others have done it. But again, I think even if I don't find an entire solution, I might hopefully find part of a solution. So yeah, that's...

Ellie: 0:40:53.9 So I've heard you say two very different things and one of them is about giving back to your community and you talked about your cousins and your siblings and other kids in your community. And another thing is about solving these grand challenges, problems in mathematics. And can we talk about what day to day life might look like if you were doing either or both of those things?

Francisco: I always thought maybe introducing people to like the work I'm doing. And I think a big part of getting people interested in your work is to show them how enthusiastic you are about yours. So I think that's probably sort of kind of what I want to have the two be connected by, just telling people, "look, this is what I do. I'm modeling the universe in terms of these, you know, however many equations and this one describes energy, this one describes, I don't know, force" and so on and so forth and "you know, this one describes gravity." I'm going on forever, but you know, "a thousand years ago, if everybody thought this was impossible or nobody even thought of describing the world in this way, but here we are now and maybe one of you guys could succeed me."

Ellie: 0:42:39.0 Cool. So who do you talk to at DePaul to think about your career ideas or your future plans?

Francisco: The professor I'm doing the independent study with, Dr. Liechty. So I actually talked to him about... Because he does mathematical physics, started talking to him about that. Because I wasn't really sure at the time whether I was going to do physics or mathematics for a PhD. So yeah, we sort of talked about what to do as a mathematical physicist and I think that's sort of what... So I sort of go to him for any advice about graduate school or anything research related or anything professional related about sort of what's in this field or what similar other fields are like that are similar to this.

Ellie: Okay. And do you talk to, are you part of like the SACNAS group or SPS or some of the other student groups in physics or in mathematics? Francisco: 0:44:07.6 I'm part of SPS, but I don't know, I didn't really feel like I fit in there sometimes, if that makes sense. SACNAS just because conferences were in October, yeah October, I never felt like it was a good time for me to go, if that makes any sense. I always felt like I was going to fall behind on my work traveling during the middle of school term, I don't know if that's something. . . It was probably just something I was raised with because I didn't really want to deal with then having to catch up. I think part of it was when I was in fifth grade, I think, I went to Mexico for like about two weeks in the middle of the school term and then I had to play catch up and I'm like, "I'm never doing this again." I mean, SACNAS is only three days, I think Thursday and Friday and then Saturday, but yeah, no, that left a lasting memory on me so I'm like, "nope."

Ellie: 0:45:26.7 So SACNAS is next week and it's all virtual and if you're just doing an independent study this semester, that might be more flexible.

Francisco: Yeah.

Ellie: Okay. You mentioned earlier that you did research like before this independent study?

Francisco: Right.

Ellie: What other research did you do?

Francisco: I've done three summer researchs. The first two were in physics and the last one was in mathematics. So first one was with Dr. Pando at DePaul and we were looking at the two-point correlation function, which is sort of. . . It's been so long since I've done this, but it was talking about bionic matter and dark energy and sort of it talked about how if there was dark energy or sort of distribution of dark matter, I'm sorry, in the early stages of the universe, it would have this weird, I guess sort of affected how matter behaves since it interacts with gravity. 0:46:41.1 And they suspect it's something along the lines of like there would be these clusters of galaxies sort of spaced out in this pattern just because of how dark matter behaves with them. So sort of the two-point correlation function, what we were looking at is to find some, if we were assuming that the universe was normally distributed,

we were hoping to find something, well, not normally distributed, uniformly. Two different things.

Ellie: Yes, I agree. Totally different distributions.

Francisco: We were trying to look for some sort of anomaly, sort of this little bump in the distribution showing the existence. Although, our codes never runned that well so we weren't able to find any, if there was any.

Ellie: And so you did your first one with Dr. Pando and then did you do your other two with DePaul people as well or did you go elsewhere for that?

Francisco: 0:47:46.8 Elsewhere. So second one was at Northwestern. I worked with Professor Schmitt, and with him I studied Type 1a supernova, supernovae I should say, there's more than one. I was happy with my work on that one and so was Professor Schmitt, at least he said he was. I hope he wasn't lying. That one I felt, I guess, more proud of myself just because I actually got some results. I found sort of these like distributions of, it measured the magnitude of the B-band, so the blue light frequency, sort of how it rises then it peaks at the supernova, and then it just starts to climb the days after. And I was able to get results that were found in similar papers. Oh, you have a cat?

Ellie: Yeah, this is my cat Judy. She's very opinionated and needs to be part of this interview right now.

Francisco: inaudible 0:49:18.6 Yeah, I guess there's more I could say about that research, but...

Ellie: No, that's all right.

Francisco: 0:49:32.2 Okay, and then the third one was the most recent one. That was with Professor inaudible 0:49:39.0. Originally, when I applied to the REU, it was going to be in partial differential equations, but the faculty said he didn't feel like he could provide a valuable research experience, only because once states started locking down and universities closing, he didn't feel he could provide me with an adequate research experience. So the people in the REU, the program was called SMART, or that was their acronym, they told me, "if you want, we could look for another faculty for you to work with, but the research might not be necessarily what you were looking for." And I said, "yeah." Why does this

sound like a bad story? I said, “yeah.” I mean, I felt like any research in math is useful just because... Maybe pure math and applied math aren’t done the same, but I feel like they’re similar enough than compared to physics and pure math or physics and applied math that I might have an idea of sort what to expect when I’m doing research in math. 0:51:09.6 So I worked with her and one of her grad students that she’s advising, his name is Jonathon, we call him JQ. That one I felt like I’ve learned a lot just because the writing was really different in math than it was in physics. So in math it’s like you never just automatically introduce some equation. You have to like write a sentence before, write a sentence after. If the sentence ends with the equation, you put a period right after it. I mean, that’s very basic stuff and I didn’t even know that. Then there’s like I’ll include this amount of background and then I’m like, “well, how much should I include and how much should I prove?” And it was just such an unusual process for me. But I really did like it. Yeah, that’s all I have to say.

Ellie: Awesome. I’m mindful of your time. Do you need to go like right at time?

Francisco: No, I think I could stay until 4:20.

Ellie: 0:52:25.4 All right. Are there things that you’d like to ask us about or questions that you have?

Francisco: I guess my first question would be what do you think I missed from my experience that I could have learned to be better prepared career wise?

Ellie: Oh, that’s a hard question. A lot of people that we’ve been talking to are talking about how they’ve connected with other students on campus and how that sense of community has helped them figure out how they want to... Like, what is the day-to-day life doing physics or of doing math. I think you have a really clear path set out for you for the next few years, right? You’re going to go do applied math in a PhD program. So in that time, while you are doing your PhD program, you will discover so many cool things about yourself and what you want to do after. So...

Francisco: 0:53:52.7 Yeah, so it’s like one thing I always hear when I was in SMART, we would have these, we called them weekly meetings and then after that happy hours. Weekly meetings were like things we wanted to talk about the program and then happy hour was

just anything. Sometimes people just drank wine because it was happy hour, just to pass the time, make conversation, lasting friendships. But one of the things they brought up a lot was demographics of the school. They always that was like maybe something they never thought they would consider, but it was something that sort of impacted them. And there were some people who said, “oh, I transferred out of this school just because, I don’t know, I felt like I was the only minority,” or something like that. So that’s something I hear about and I never really took that into consideration until this year, but I’m not much of a social person so I don’t think that would be like the biggest impact on me.

Ellie: Is that something you’re thinking about now that you’re thinking about where to go to grad school?

Francisco: 0:55:03.5 A little bit. I think more in terms of, this sounds really bad because I’m kind of chubby, food. It sounds weird, but I have friends that... I have one friend, she’s in Iowa and there’s like really nothing, there’s hardly any Mexican food around, so she said it just feels weird. I’m like, “huh, I never thought of eating...” I mean, this may sound inaudible 0:55:31.7 but like I eat tortillas almost every day. So now to have to go a day or even a week without them just seems weird. I want to get comfortable with being uncomfortable, at the same time, I don’t know if I want to change like entire aspects of my life. So demographics and then living situations, you know, how much does the school give you as a stipend? What’s the average cost of an apartment or of a house? That’s other stuff people mentioned, and I sort of need to look into that too, once programs start accepting me, I think. Although it might not be the best call. Yeah, I think that’s about as much as I have to say about what I feel like I learned from them that wasn’t academic related.

Ellie: 0:56:51.0 Cool. Are there any things you wish that we had asked about and we didn’t ask about?

Francisco: I’ll pass and probably come back to that later.

Ellie: Okay. Okay. And do you have more questions for me about like anything really? I mean, I’m easy. Francisco: Are we going to use this, or I guess it will probably be Dr. K that will use it, sort of use this in terms of... Hopefully, I would assume it’s just to change the department, but was there like any idea of what like Dr. K wanted to do or does she

want to first get the information before she starts anything?

Ellie: I mean, I can tell you a little bit about what she's planning, but a lot of the details of it are going to depend on, you know, what a physics student inaudible 0:58:09.9 and so we need information about that. But in general, the scope here is that she's going to develop some activities and like ways to think and be to be used in physics classes across the curriculum around career preparation and developing a sense of purpose. So it's not like it's a whole new course, it's activities to be integrated into existing physics courses. And that she'll be primarily developing these over winter quarter and then during spring quarter, she'll share them with the other physics faculty and get their feedback. And then they'll first come in front of students in fall quarter. Next fall, not this fall.

Francisco: 0:59:08.2 Yeah. Okay. And I could not think of any questions, so I think that's about it.

Ellie: Thanks for chatting with us about physics and applied math and about how you're thinking about PDE's and how to incorporate them into your life, because this is cool stuff. Chris, do you have any last questions?

Chris: Yeah, I have a quick one. I got to say, this was a super fun interview to be a part of. I love math and so meeting other people who are also loving physics and math as a pair is really exciting. Question for you, at DePaul, how well do you feel, if at all, did your courses in math and or physics prep you for computational numerical solutions to these equations that you love so much?

Francisco: 1:00:09.9 So I felt prepared for the Laplace equation and the heat equation, but those are the ones that mostly show up in physics and are in most physics textbooks, but not so much for the KdV equation, but I think part of that is that this is sort of a beast of its own.

Chris: So you haven't done a lot of numerical solving then, for these things?

Francisco: So numerically, yeah, I think there was the Monte Carlo method, which I think is also called the inaudible 1:00:44.5 for solving. What was it called? The Laplace equation and then there was also the Euler method, the... I don't remember the other name, but it was kappa, and then I think it began with a G method. So we learned sort of like those

numerical methods, the reverse-Euler method, then there was the method with ordering, it was like going up to the  $n$ th order of the Euler equation, not Euler equation, sorry, the Euler method.

Chris: That's awesome. Okay. Thank you.

Ellie: Yeah, that's cool.

Francisco: Yeah.

Ellie: 1:01:34.6 All right. Well, that's all the stuff I've got. Chris, all the stuff you've got?

Chris: That's all I got.

Ellie: All right. Do you have more questions for us?

Francisco: No.

Ellie: Then that's all we've all got. Thank you so much for chatting with us today. If you find later that you develop more questions, we're always happy to chat with you again. Shoot me an email. You can also email Dr. K with questions.

Francisco: Okay.

Ellie: All right. Thank you so much.

Francisco: No problem. All right. Bye. Have a good day.

# Appendix C

## Francisco's interview transcript:

### Round 2

DePaul-Francisco-Follow up-Transcript

Chris: All right. And now that we're recording, you are okay to participate in this study?

Francisco: Yes.

Chris: Excellent, excellent. And we're good to go then, that's all the things. I had to double check my protocol there, but we are set. So let's begin. Tell me, in the last roughly six or seven months, you know, what has happened in life for you? I think in your last interview, you said you were going to graduate like around December sometime.

Francisco: Yeah, so I actually graduated at the end of November because sometimes it takes a while to certify your degree and everything, I assumed it was going to be in December, but it went a little faster than I thought. I applied to some graduate schools, got a couple offers, applied to eight, got into four PhD's and then one BRIDGE program. Should I name them or...?

Chris: You can name them if you like or, you know, just a general idea in particular what things are interesting you the most out of the offers you have?

Francisco: So the four PhD offers I got they were all in mathematics or applied math. Some schools have their math and applied math as the same program, just you take different

routes. So I got an offer from the University of Minnesota at the Twin Cities and University of Colorado Boulder, their applied math program, IIT, which is the Illinois Institute of Technology, it's in Chicago. Like I said, it doesn't really help since you don't inaudible 0:01:51.2 and the one school I selected was the University of Texas at Austin.

Chris: Okay, so what's going on... Sorry, University of...?

Francisco: Texas at Austin.

Chris: 0:02:01.5 Oh, my goodness. So what are you doing there that you made you decide this is what I want to do, this is where I want to go?

Francisco: Well, my choices were between Minnesota and UT Austin, and what made me narrow down to those two is that there's just a lot to do there, there's just like a lot of research topics, so I'm like, you know, just in case because I wanted to do something with PDE's and I still kind of do but more from an applied standpoint, so some of the things I learned you can do with PDE's is like machine learning, stuff like that, which is kind of what sparked my interest lately. So I had an interest in that really to... And UT Austin and the University of Minnesota both not only have research in that but in other fields, so maybe in case I wanted to take something more pure in the math world or maybe some more applied I can just go back and forth between researches before I've got to start my dissertation and all that. In the end, what made me go with Austin though is I just felt that the program felt more challenging. It looked harder, but at the same time, it looked like I would gain more from it, if that makes any sense.

Chris: Yeah, for sure.

Francisco: I also got an offer to the BRIDGE program at Michigan.

Chris: Tell me a little bit about the BRIDGE programs. What are those all about? I'm not familiar.

Francisco: So they're technically master programs, but essentially, the goal for the BRIDGE programs is you didn't quite qualify for the PhD programs, but you qualified for the master's, but they also think that you would do well in the master's program and hopefully, if you do well enough, they'll just accept you automatically, maybe with just like a few steps but not like the whole application process, right into the PhD program.

Chris: 0:04:10.5 Gotcha. So all of these applications were focused on your PhD in the long run?

Francisco: Yeah.

Chris: What are you hoping to do with that?

Francisco: Machine learning is like the one thing that comes to mind. Like, there's like a lot of work in industry, like surprisingly, half of the students who... And this is also why I was considering Minnesota a lot over UT Austin for a while was just in Minnesota like half of the people receive their PhD end up working in industry. And a lot of it now is just like using mathematical methods to like deal with like machine learning, so like developing algorithms so that you could like... Sometimes you might not be able to determine like an equation or certain models to like fit your data. So sometimes you would just leave that up to the machine inaudible 0:05:14.1 and all that other stuff we try to learn as much as possible.

The other thing is also data science, which sort of goes hand in hand with machine learning, especially doing things like I have one friend who does research in biology. They were sort of studying like the bone structures, I'm not entirely sure how, but he's like, "we always had to make these initial guesses" and I'm like, "oh yeah, that's what I'm trying to do." Like, because the one thing I hate about modeling is you have to make an initial guess, and if it's a really bad initial guess it spews out nonsense, and you're just like aww. You have to start all over because sometimes the code runs for like half an hour and you're just like...

0:05:59.5 So that's also just one thing I'm trying to think of too is just like kind of like working with data in that sense. I think that's what drew me to physics to begin with just because there's like a lot of data in physics because it's been around for a long time, so roughly the equivalent of maybe four or five Betty Whites. So yeah, it's been around forever, and I just realized with applied math you could a lot more and not just things necessarily limited to physics, but you know, things with biology, chemistry, even engineering, although I'm not too familiar with that at all. I know it's just like it's sort of like you have a wide range.

Chris: And so you're looking at data science and you're looking at machine learning. In the last kind of few months, you've been doing applications. What else have you been doing? Have you been working in the last few months or taking some classes or taking some time off? What's been going on for you?

Francisco: inaudible 0:07:07.9 I worked part time as a tutor, but also it was just time off. I feel like it might have been too much time off because now I'm worried about going back to school and just trying to get back into the system of studying and homework and, you know, just like stressing out for classes. But now in the summer I'm just taking a class in measure theory and real analysis, basically. Just because it will give me a leg up in the... So the measure theory class is with an instructor from DePaul, but he just let me observe the class and sort of participate without having to pay anything, so that's nice.

0:07:50.9 I think it will give me a leg up in the math program at UT Austin just because real analysis, and measure theory in general, are just really hard things to do, so unless you don't have like a good understanding of the basis it's just incredibly difficult to learn. And understanding things like... So one of the things you have to do if you want to do like, you know, machine learning or, you know, your optimization of data sets and stuff like that is functional analysis, which is just like... I'm not sure if you're familiar with functional analysis or the term at least?

Chris: I don't think so.

Francisco: You're familiar with the Euler-Lagrange equations, right?

Chris: Surely am.

Francisco: So that's a specific type of functional analysis. It's like you're trying to find a function that fits a... You're not necessarily finding the variables, but you're actually finding the function, and that's what the Euler-Lagrange equations do, you find the function.

Chris: Right. You treat the function as a variable thing that you can find.

Francisco: Yeah, so that's essentially what we're doing with functional analysis. Like, well, if the whole point of modeling is to find a function or a model to, you know, apply to this data, then functional analysis should be the thing we use, the tool we use. And that requires a lot of analysis, you know, talking about compact space, compliment space, rules,

or you know, multi-differential functions. It's stuff like that, that you need like a grounding in analysis, real analysis, before you can start doing functional analysis.

Chris: Kind of machine learning and data science in particular is the thing you wanted to pursue next. When did that materialize?

Francisco: 0:09:50.6 So part of it was just me studying PDEs, and I went down this weird rabbit hole of just like, oh, well, you know, PDEs are used to find functional analysis, which sometimes helps people develop algorithms, and I'm just like entering like a weird dark loop, like down the rabbit hole. Yeah, and I mean, I wouldn't necessarily say that that's my only interest, so I think applied math I'm trying to get the most out of it, not just within machine learning, although I think that would be like a really cool thing to specialize in. But just like applying math in general because sometimes you don't quite see the connection between your data and the physical reality and sort of making a mathematical foundation too.

Like, I think for me the one constant thing is like quantum. I don't know, I mean, now that I studied it, you kind of understand the math but you wouldn't really think, you know, particles they're either momentum or position is probabilistic. You would think it's more like classical mechanics, where it's like you just determine it, you wouldn't think it's like, oh, well, this is, you know, a Gaussian distribution. You're like why would it be Gaussian? Why doesn't it follow this route? And then, you know, there's just all this other stuff that's uncertainty principles and stuff like that, and you're just like oh.

Chris: Behind the physics isn't super obvious at first glance and vice versa.

Francisco: Yeah, no, and that's some kind of one thing that I realized with the math is like it's not obvious, so I mean, even if the physics sort of became obvious the math is not always that easy, sort of like general relativity. It's, you know, Einstein kind of had a foundation for it but the math was just so... It took a while for him to learn the math before he could even develop equations and everything.

Chris: 0:12:01.2 Differential geometry's a whole other ball game.

Francisco: Yeah. I still don't get it, to be honest. Chris: Okay. Fantastic. So in the last six months it seems like you've kind of been doing a lot of waiting since the applications. What is your career, you know, you're thinking of grad school right now, and you're thinking

something to do with data analysis and machine learning. Do you have any thoughts about what particularly you want to do? Do you want to go into industry? Do you want to take this and go into academia? Do you want to go into teaching? Like, what's on your mind for next steps?

Francisco: Industry or labs, national labs. So Fermilab I know has like a program with like data analysis, and that's kind of something that I really just want to learn to do. Also, a place like Amazon, surprisingly, you know, they offer you internships for the summer and they pay you a lot and sometimes it matches maybe a good chunk of what they pay you throughout the year in grad school just because they're very rich, wealthy, endowed.

Chris: Cool. So compared to where you were, you know, earlier this year just before graduating, like have your thoughts for jobs changed since graduation?

Francisco: Yeah, yeah. I thought I was going to end up being a professor, but when I found out there's like, you know, industries are paying you a lot because the future is now heavily involved with computers that they just are paying people and seeking people who just like have a knowledge and a good understanding of data analysis, that they're just willing to pay you at a higher rate. You know, money shouldn't be everything, but you want to live comfortably, and sort of our society's just built on that, so I can't really escape that.

Chris: 0:14:07.6 Yep. Yep. Need to get paid.

Francisco: Yeah. I mean, if money was never an issue, then I don't think I would have... I don't think I would be worried about a lot of things, but it's not the way the world works.

Chris: I hear you. All right, so then since your ideas for careers have changed, how have your ideas for what you need to do changed, right? Like, your steps for getting to where you want to be. Part of that is grad school. What else?

Francisco: Yeah, I mean, grad school and all the stuff that comes into like thesis and, you know, your PI and stuff like that. But outside of academia, or grad school I should say, sorry, it's things like networking, developing like skills that you don't necessarily learn in the classroom. So like skills like coding or, you know, like other skills that you might need in companies. One of the things I've found is like along with like coding software that, you know, people don't teach you and like inaudible 0:15:15.3 is something that people still

use. Other things I would say is probably like teaching and public speaking. That's not necessarily something you learn in a math class, but it's something you need to master, especially if you're trying to propose an idea to a company or to directors. Like, you can't just say oh, well, I'll just expect them to... You have to like go into like while you're going into all the minor details with your team and anyone that's involved in the project of how to develop this thing, you need to also explain to your higher ups like why is it that we're funding you. It's things like, well, you could do this and this, and they're like, "well, why does that matter?" and I'm like, "you could then apply it to this" and learn to speak people's language, which is-

Chris: 0:16:13.0 How is the PhD helping you reach your long-term goal as opposed to a master's degree or just your undergrad?

Francisco: So I would say a PhD is more like... It helps you more with research. I think that's the main difference that I've always gotten from master's to PhD's. Not necessarily to say that if you're a master's student you don't do research, you do, but there's really those four years after you're done taking your, you know, inaudible 0:16:43.1 thing, you just spend a lot of time developing independent research, sort of you can't really refer to a textbook of what you're doing because essentially, what you're doing is your own research. You have to like sort of find, you know, knowledge, you know, first you have to find a problem and then you have to see if you can actually solve the problem or at least that there's a way of attempting it, otherwise it might take more than a PhD and four years to do that. And then, you know, just start accumulating all the knowledge that's in your possession, so it's stuff you learn in class, but then there's also stuff you haven't learned that, you know, there's probably not a class on, just start pulling things up. And I think that's one of the hardest things about really research in anything or developing anything new is just you don't know where to begin. Sometimes you do, and that's nice, other times it's not that simple either because, you know, this field is so new that people aren't really sure what direction they're supposed to go in. And, you know, there's a lot of people that worked on it before you that just either got stuck halfway through or just, yeah, are stuck in the same position or are like been going in the wrong direction for so many years and they didn't just find out until

recently and then they have to go back several steps to find out where they went wrong and it's just... In four years, maybe four to three years of doing a PhD would probably give me some patience in that.

0:18:25.4 I think it's just one of the things I have to learn. Research is slow, it's very slow, very long, very... At times, you just hate it. You know, you're human after all, you're not going to be happy about everything. Sometimes you just need to learn that you didn't solve it, you didn't solve it, you just either move on or just take a different route. Yeah, and it's, you know, it's easier when you say it like that, but for some people with their life work it's not easy to get there.

Chris: You're hoping your PhD will kind of teach you some of those skills, rolling with the punches, little bit of lateral thinking, what are some ways I could get around the block rather than going through it, that sort of thing.

Francisco: Yeah, and then also just getting used to people criticizing your work, well, not criticizing but like, you know, criticism not criticized but criticism.

Chris: Criticism.

Francisco: Yeah, would probably be a better word. It's just like you're not a researcher, you're not going to be perfect, you're probably going to be horrible, you're probably going to be making a lot of mistakes and all that people are going to point out a lot of things that they don't like that you're doing. And you're just like, okay, okay, okay, but you just learn to move on, you learn to deal with it. You learn to grow from it, especially if they give you feedback that's actually useful instead of just pointing out the errors, which I think is also something you need to learn that it's not always going to be there. Especially if, you know, you're presenting work to people who have no idea of how any of this is done, they won't provide you any feedback, they'll just say, "no, and this is why we don't like it." You learn to deal with that. I mean, I know that sounds like a first world issue. I don't know why.

Chris: 0:20:20.9 I mean, you know, but it's an important issue, right? People are going to give you feedback. Sometimes they'll be constructive and decent about it, and sometimes, they're going to be jerks and you have to learn to deal with it and ignore the jerks and take the constructive feedback and make your work stronger.

Francisco: Yeah, definitely. And have some... Yeah, I think that's why I wanted to do my PhD. Also like I always wanted to go for a PhD, just because I've made it this far, I'm like, "let's see how far I can go. The sky's the limit." I guess at this point, more is the limit, but whatever.

Chris: Well, and let's kind of springboard from there. You've always wanted a PhD. You're thinking about kind of the new skills it could generate. What other factors have been kind of driving your decisions in these months since you've graduated, right, when you're thinking about careers?

Francisco: I guess just the environment we're in at the moment. There's just like... Maybe it will die down, I'm not into commerce, I don't know what the demands are for, you know, a given population or a given nation, but sort of there's just like a big demand at the moment for, you know, all things tech. Self-driving cars, you know, to electric cars, involving Elon Musk, you know, all these new ways of shopping that we didn't think were possible, you know, I didn't even think were possible 10 years ago inaudible 0:22:06.0 But you know, it's like there's people trying to develop drones to like have your stuff delivered to you.

0:22:16.9 There's people trying to have... I was speaking with a friend earlier today where his fiancée is a med student and like one of the things is like they have like these little, I don't know, it's like a tube, very thin, and they go into your belly button and then they try to do surgery without cutting you, like opening up your stomach or whatever, and then just having the tools be sent in and just work with it. And I'm just like, "how does that work?" and he's like, "I don't know. It's just something they're using."

I have another friend who's going to school, I think it's Vanderbilt, I just know it's in Tennessee, I don't remember what the name of the school is though, it could be Vanderbilt. She is studying, essentially, nanotech and cancer treatment and it's like a new field, so you know, machine learning like how do you program these little bots to like only attack the tumor, only attack the tumor cells and not attack everything around it because that's sort of the big issue of like radiation and radiation therapy is that like you shoot the radiation, you attack the tumor, but the downside is you also attack the healthy tissue that you do

more harm in the end.

Chris: Yeah, it's like science fiction is becoming reality more and more.

Francisco: Yeah, I'm just waiting for the flying cars now and the flying skateboards. inaudible 0:23:51.0 six years ago, but Michael J. Fox lied.

Chris: So what about family or community or friends as you're thinking about your PhD and careers? How are they factoring into your plans? Are they kind of important to you or are you thinking it's all right if you're further away?

Francisco: 0:24:12.1 I love my family. My mom, I think, she's probably the most important person to me. That being said, I can't... Well, first off, like my family, they're all immigrants, so my parents were born in Mexico and my mom came here with her parents... Give me a sec inaudible0:24:38.0. Yeah, my parents are immigrants. My mom came here when she was a girl, first time with her grandmother, and then second time with her parents. My dad came here by himself when he was 16. So, you know, moving away from family isn't an odd thing for us, at least not within this generation and the last one before that, but it's definitely been hard. It's not necessarily easy leaving your family behind, but at the same time it's like, you know, they understand that if you can't find work where you're at you need to go out somewhere else.

Even though my dad came here by himself when he was 16, he sort of understands that because he left behind his mom and his brothers and his sisters and his father too, looking for work. So it's not easy leaving people behind, but I guess it's just something you need to do in order to, you know, succeed, and find work and make a good living for yourself and your family. Especially with, you know, there's various factors, but your parents age, so they can't work forever. You know, things are just becoming pricey like houses and whatnot, so you know, it's almost impossible to afford a home at times, and so you need to find a job that pays you extremely well to buy a house if you want a house.

0:26:41.8 And then other stuff is just like finding satisfaction in my work because, you know, a lot of my relatives work in, you know, long either nine to five or from like 11am all the way up to 7am. I mean, 11pm all the way up to 7am, so it's just like intensive labor and it's just like not necessarily something you want because then you see them come home

and they're tired and they can't do much. Not to say that the work in an office or at school is not tiring, it is. For some reason doing things through Zoom is always tiring, more tiring than in person. I still don't understand why that is, but I'm sure there's a psychic reason behind it. Yeah, so like all those things factor into like a career. Like, I don't want to do what my dad did, which was work in a factory. It seems like more of a first world thing, but I really don't want to do a lot of physically demanding jobs.

Chris: Right. Right, right.

Francisco: I was always just really good at math, so I'm like I might as well just, you know, I wasn't physically, athletically fit, so I might as well just explore the one talent I have and just go with it.

Chris: Fair enough. Take the thing you love and roll with it, right?

Francisco: Yeah. And math was just the one thing I was really good at and so I ended up just loving it.

Chris: 0:28:29.6 Yeah. Okay. All right, well, let's continue with that then. What is job satisfaction, right? One of the things we discussed last time we met and one of the things DePaul puts an emphasis on is, you know, sense of purpose, what's meaningful to you, what's satisfying to you, right? So what is? What is the sense of purpose and what are the things you love that drive job satisfaction for you?

Francisco: It's hard to say, really. I think more of it is just appreciation. I mean, it's a very simple thing. People don't really mention that, but I think it carries you a long way, especially if you work jobs where you're just not happy, but you just have to do it for the pay. It just seems like... I mean, even if it's a job you like, not every day is going to be a good day, but it makes the day a lot easier when you feel appreciated, when you feel, you know, like you made an impact on someone's life.

Chris: Yeah, you want your work to be valuable and appreciated by someone, right?

Francisco: Yeah, I mean, and you don't quite see that in industry. It's not something people think of, but I think my satisfaction would be just like developing products or developing algorithms or even, you know, working in a national lab and developing technology that just helps change people's lives. I think one thing that industries are just really consid-

erate by now, and it just might be because of social pressure not for any moral or financial reason, at least. I mean, I should keep my politics to myself, but you know, green energy and making things that are more environmentally friendly, I would say is the best word for that, you know, people are kind of like develop cars that either don't consume as much gasoline or fossil fuel or, you know, just altogether don't use it. And, you know, just along with that try to develop like, you know, electric cars where the stations you charge them at aren't parked by like coal or, you know, other forms of fossil fuel that generate electricity. They try to also limit where the electricity comes from.

Chris: 0:30:59.9 Why is that important to you?

Francisco: I really don't want to be under water. It's that simple for me. I don't know. I guess also part of it is just human and human exceptionalism. I know that's not necessarily a great rational thought, but it is... I mean, we're humans, we're like driven by emotion I would say more than reason. At least that's my thought on how humanity sort of functions, and I think part of us just wants to survive and, you know, live on for generations. I don't really see us moving to Mars in the next century, so I don't think we can just pack up and leave.

So for the generations that come after us, I don't necessarily want them to inherit nearly a century and a half of environmental... But also, at the same time, I really, really like air conditioning, so it's kind of hard to give up, you know, your way of living, but also trying to protect the planet. I know that sounds selfish, there's no denying that, and there's really no excuse for me on that, so I might as well try to work where I'm at. And then like other things that improve people's lives is, you know, just... I don't know, I think it's just where people could see what you've done and just put it to multiple uses, good uses. inaudible 0:32:41.0 people could use it for horrible things, but I can't control everything, unfortunately.

0:32:46.5 So other things with like machine learning is, you know, like hopefully develop an algorithm for say nanobots like attack tumors and only cancer cells, which you know, there's a lot of thought into it because cancer cells mutate rapidly, so you can't have it specifically attack one type of DNA because you've got to account for the mutations, but if you have the DNA very similar it could start attacking your own cells and that's not good

either. So that, you know, keep kind of what mutations you should be looking out for and how to make sure it's not going to attack healthy cells. inaudible 0:33:35.6

Chris: Some of this harks back to the idea of like doing good in the world or helping other people or, you know, helping the planet.

Francisco: Yeah, yeah. I mean, I wanted to be a doctor as a kid, then I realized I don't really like blood, and for some reason as a kid, I always assumed being a doctor means also doing surgery and I don't want to do surgery. That stuff like makes me faint. It's not a great thing if you're going to be a doctor and you faint in the middle of the surgery, like, oh no.

Chris: Right, right. Suboptimal if the doctor needs help up in the surgery room.

Francisco: Or even if it's not nanobots, just develop new tools for doctors, you know, like some sort of scanner.

Chris: 0:34:24.9 So it sounds like you're conceptualizing doing good in the world as like the research or the industry work you're going to do is going to help the development of technology that will help people.

Francisco: Yeah, and I mean, that might not always be the case. I'm aware of that. Especially they patinize everything.

Chris: Are there other things that you think of as like good things that should be part of your career, that you want to be part of your career, that are helping people or...?

Francisco: No, I think it's just stuff that involves like, you know, producing or just making things more comfortable for people. Assuring, you know, at least that there will be a planet for the next few generations. I can't really speak for what's inaudible 0:35:15.1 stuff like that, yeah.

Chris: And has this changed between now and kind of before you graduated? The things you think of as important, meaningful, the things that are good in the world that you ought to be doing.

Francisco: Not necessarily the things that are good in the world, but like things that I think I could do for the world have definitely changed.

Chris: In what ways?

Francisco: I don't know. I thought I could have been an educator, but sort of tutoring I realized might not necessarily be the best fit for me. Not to say that... There were some kids that I really liked tutoring, they got it, they just like you ask them, and they'll work with you, even if they're struggling, they'll work with you and you'll be with them like every step of the way and try to help them do the steps on their own and they'll, you know, start working with you. But other kids are a lot tougher and that's kind of like... I'm patient with them, but at the same time, I'm like I don't know if I just want to do this a lot, which is not the sign of a good educator, I would say. Like, I don't want to be a teacher who just like gives up on a kid just because they're just like tired and they're like... Because I've known teachers like that and teachers they... To be able to work with kids that are difficult to work with is something incredibly special, I would say.

Chris: 0:36:49.8 Right. Why did you originally want to be an educator?

Francisco: I don't know. I think it was just something I saw myself doing. There was probably no reason other than it's just something I saw myself doing and, yeah. It's like the same reason as when you're a kid and you see yourself like, you know, being a cowboy. It's not really a thriving industry in today's world. It's just maybe part of the culture, maybe just how you see yourself.

Chris: Can you think of like people or events or things that made you think like, "yeah, I could be a teacher"?

Francisco: Events, events... Probably just like high school, there was a few good teachers I really liked. But then again, I think in high school, the difference is that like the kids you work with are very mature, a lot of those kids I worked with are in elementary. Honestly, going for a PhD, I'll probably be working with college students, but still, it's... I don't think I have... Also, I kind of like stutter a lot and sort of take odd pauses in between talking, and I know it seems like I'm into something and that's not necessarily the image I want to portray or project onto people. So that's also something I've considered, like image is a very important thing for educators, you know, you shouldn't judge a book by its cover, but if you don't sound confident or act confident, you know, that doesn't necessarily sound like it's going to be a good time for the students and that's not necessarily something that

I think would work as being an educator, I think.

Chris: 0:38:44.6 Gotcha. So over the last few months, you know, since graduation or even a little before graduation, how have you been thinking about, or how has your thinking about what's meaningful to you changed and what's been supporting that thinking?

Francisco: Oh, you're talking in terms of like career wise, right?

Chris: Yeah, I mean, career wise or in general.

Francisco: I think for me family has always been important. I have a grandfather who I'm really close to, he's like turning 91 in November, I think. He's very old and when someone's very old you think of death and like they're not going to be around forever. You don't really think that. You know it, but you don't think it. Just like I know I'm going to die one day, but at the same time, I'm 23, I'm invincible. You don't think a car's going to hit you and you're going to die, you're like, "oh, I'll just like walk it off" or something. You never think about it until... That's what I'm saying, I don't think no matter how much you try to prepare for it or try to like every scenario, you're just going to accept and be like, yep, that's it.

So I mean, family is one thing. And I don't know why that influences me, but it just does, so every time I do something I always just announce it to my grandfather, like, "oh, I'm doing this and this," and he's like, "all right," and he doesn't understand anything of it. Part of it is a language issue. Everything I learn I learn in English. I can't necessarily translate it all into Spanish perfectly. Another thing is that like he only went to primary school, so like up to sixth grade. And it's like you can't really explain to someone who studied at sixth grade like every little thing and every little process of what you're studying, unless you're just going to give a big lecture. And I don't think someone wants to sit through that, where you explain something for like five hours of like developing code, doing a loop, and all that stuff, and you know, how you would have that work for a machine and a machine do it by itself, but you know. 0:41:01.4 Honestly, I would say family is probably the main reason I will continue education. They've always encouraged me to go to school. I remember when I was a kid, I didn't necessarily study. Until like eighth grade I used to struggle a lot in school and somehow, I just changed in high school. I think it's just because the option of taking

more science and more math courses sort of fit my interests, which just made me succeed better in school. Whereas, elementary school was more literature, poetry, art, and that was never my... I can do calculus. I can't explain to you what Shakespeare means in any of his writings. Like, I don't know. He's a ghost, Hamlet and spooky dooky.

Chris: Yep, yep, yep. Okay. My goodness, I am looking at the time, and time is just flying by.

Francisco: I know.

Chris: Do you need to leave relatively promptly at the end of the interview?

Francisco: No.

Chris: Okay. All right. Well, I've got a couple more questions that I'd like to follow up with then in the time we have left.

Francisco: Okay.

Chris: So I know you're no longer at DePaul really as an undergrad student, but as you were wrapping up your undergrad, were there people or resources at DePaul who were helping you make these decisions about grad school and all of that?

Francisco: Yeah, should I give you names or...?

Chris: You can if you want. You can summarize if you prefer.

Francisco: 0:42:47.8 Some of the people were Jesus Pando, Dr. K would just call her Mary Bridget, but we always called her Dr. K, I guess, because people had trouble saying her last name. Dr. Kashina, her first name is Russian, it begins with a Y, Y V E, I can't pronounce it, why everybody says just call her Dr. Kashina because nobody can pronounce her first name.

Chris: Same situation with Mary Bridget, but kind of backwards?

Francisco: Yeah. And then Dr.-

Chris: How were they helping you? What kind of things did you talk to them about?

Francisco: What my interests were and they were like, "oh, you should try this school and this school." Dr. Kashina actually helped me a lot. She suggested this program to me called the Math Alliance, where you know, you would be paired with a faculty at your home institution, so a faculty member at DePaul. I didn't really meet her, I just talked to her

through email, her name was Bridget, I think it was Bridget Tenner.

And then another faculty member at another school, and I got paired up with a faculty member named Fadil Santosa, who originally worked at University of Minnesota Twin Cities, but then he moved over to John Hopkins, and he just, you know, also helped me with like deciding what schools best fit my research interests, my. . . Another thing you always consider is I met some people who were like, “do you want to live in the cold? Do you want to live in the summer?” not the summer, but the warmer climates. Demographics too, do you want to live in a college town? Do you want to live in a city? Do you want to live in a place that’s incredibly diverse? Do you want to live in a not so diverse place? I don’t know.

Chris: 0:45:05.2 And what were some of the answers to those questions for you? Were those big factors for you or were you not very concerned about location?

Francisco: Location not so much. Mainly, I just wanted to be in the continental US, so not Hawaii, not Alaska.

Chris: What was the preference? Why the continental US?

Francisco: Because it’s a lot easier traveling. Especially when I have to like, you know, move and drive. I don’t want to go through Canada, and I really don’t want to pay to ship my stuff over or inaudible 0:45:42.4.

Chris: And did you talk much about where you’re going to. . . Like, is location a big factor for where you end up long term after your PhD?

Francisco: Not really. I think my biggest factor was just research. I mean, as long as I was in the continental US, I don’t think I was going to be too picky, but I did want to be within a city, so I didn’t want to go to places to like, say, I think Williams. It’s a school my sister got into, but she said that she didn’t pick that school because it’s like very rural. I can never say that word correctly. It was very rural and one of her teachers was like, “you know, like from the airport to the campus is like a two-hour drive. Do you have anyone to take you from there to the campus?” My sister’s like, “I didn’t even know it was a two-hour drive.” And that’s why she ended up going to Emory, which is in the city, in Atlanta.

Chris: Right. Easier access.

Francisco: Sort of why I chose, you know, schools within big cities, or at least college

towns that are close to big cities. So like Ann Arbor is not that far from like Detroit or Chicago, it's like a four-hour drive, I think, from Chicago. And Indianapolis also has like a big airport, but it's also not that far from Chicago. Boulder is not that far from Denver. Wisconsin Madison is, I think, maybe two hours away from Chicago. IIT is in Chicago. And then Harvard and MIT, but I didn't get into those, but those are in Cambridge and they're very close to Boston.

Chris: 0:47:35.0 Gotcha. Okay. Well then, you know, I guess my question to you is do you have anything else you want to share with us? Things that you feel we missed or things you want to talk about?

Francisco: I guess I wish there was somewhat of a career fair at DePaul, at least with physics. I know it sounds like a high school thing, but I think sometimes you don't know what you can do with a physics degree. It's more than just either go straight to a PhD program or become a teacher. I know one friend of mine, she works at an electronics company and, you know, one of the things you can do in physics is study a lot of electronics and just inaudible 0:48:33.6 stuff like that. But you know, it's like because one of the hard parts about circuit boarding and circuit boards is like making sure you have the right resistance, the right amplifiers, the right buffers, and stuff like that to make sure that you have things like controllers or, you know, any electronic device work correctly, so it behaves correctly. So you have to make sure there's no, I guess, inaudible 0:49:09.5 or anything like that. That's what she's doing right now, so she decided not to pursue a PhD and she's working on electronics. She had connections with faculty members who knew people.

Chris: Hop right into industry?

Francisco: 0:49:26.5 Yeah. I mean, that's I think, something that wasn't necessarily always taught at DePaul. They mentioned it a couple of times, but it's not something I think I would give much thought to. It's just like there's more than just academia and education when it comes to getting a physics degree. There's a lot of jobs in industry, there's a lot of jobs in research. I mean, that one was somewhat obvious, but you know, there's just a lot you can do. Sometimes when people think, oh, I want to work in research, they think you need to do a PhD. That's not necessarily the case. You can't necessarily do your own

research, but you could be a part of team.

Chris: Right. Nobody works alone in the long run, so...

Francisco: Yeah. I knew another student, he worked in Fermilab. He just had his bachelors and, yeah, he worked at Fermilab for a while.

Chris: Every researcher needs a team of people with them and not everybody needs a doctorate to be involved. True enough.

Francisco: Yeah. But I think, as I said, I always wanted to pursue a PhD just because I'm like, well, what's stopping me now? Maybe that was a little too overconfident, maybe a little too cocky, but I don't regret it.

Chris: Perfect.

Francisco: But I do think some students thought that that was their only option, and I just wish that something we could have discussed a little bit more. Not all students can make it to like seminars or colloquiums, or maybe not all students found appeal to it, because sometimes it was more research driven, more academic driven. I feel like maybe mention it once or twice in class for like a brief five, 10 minutes might have been, I would say, helpful.

Chris: 0:51:31.3 Okay. Good to know. Hien, do you have any follow up questions that you would like to ask?

Francisco: No. Oh, sorry.

Hien: I'm sorry. Yeah, I guess that I am allowed to ask a question right now, right?

Chris: Go for it.

Hien: Yeah, so I just have a very quick question for you about the idea of machine learning. So it seems to be a very new idea compared to what you were thinking six months ago. So I am just curious, where does this idea come from? Like, did you discover this idea by yourself, or did you hear from someone else or like how did you discover the idea of working in industry or the machine learning?

Francisco: So I knew about it before. I just didn't know how much math it involved until I spoke with someone, I'm like, "well, I want to do research in PDE's" and they're like, "is there any other interests you have?" I'm like, "I like coding and I like machine learning optimization." They're like, "have you tried... Well, you can do machine learning that's

just like PDEs” I’m like, “what?” So there’s like different methods of machine learning. One of them is called the inaudible 0:52:44.3 so it’s, sort of dumb it down a bit, it’s like analyzing data using like PDEs and one method is the Laplace equation, so it’s like you’re kind of constructing like models using the Laplace equation where you. . . I don’t know how familiar you guys are with Laplace equations, I assume somewhat familiar.

Chris: Somewhat. Can you use like a matrix solutions to the Laplace equation? Is that the kind of thing you’re getting at here?

Francisco: 0:53:20.7 Sort of. So it’s. . . You sort of, I guess, one of the things that you do with like PDE’s is that you could sort of start approximating surfaces and sort of just start inaudible 0:53:38.0 them, but the Laplace equations are sort of like within the boundaries, so not excluding the boundary, but everything within it. So the space you’re looking at, there’s no extremes, no maximums, no minimums, those only occur on the boundaries, like the edges of the square, the inaudible 0:53:59.4 boundary, I believe, is one of the boundaries. And you sort of just work with that behavior and, you know, figure out well, how would this, you know, behave under these PDE’s or similar like that. There’s other methods that have been. . . Another one is called inaudible 0:54:21.0 method, which is like the Laplace equation, but you know, similar to like the inaudible 0:54:25.4 and Laplace equation, there’s just an extra function.

Chris: Yep. Yeah, right, inaudible 0:54:32.7 is not homogenous.

Francisco: Yeah. So that’s also another thing. It’s just working with these functions and. . .

Chris: Integrative solutions to PDE’s.

Francisco: Yeah. I mean, that’s one method, but then it’s like the main purpose of that is just to like help the machine know how to interpret this data, know how to interpret it and sort of learn how to build models from it is like the main point. And you know, sometimes machines can’t learn by themselves, sometimes you want to have them learn by themselves, so just give them like this little nugget of like information, and then from there it just starts building up methods and model and remodel or correct itself.

Chris: 0:55:22.6 Cool.

Francisco: That's kind of the point with Laplace equations is you can teach the machine how to solve things, and so one of the easiest things to solve, while also being challenging, are Laplace equations.

Chris: I am all out of follow up questions. Hien, do you have any additional follow up questions?

Hien: No. I am good.

Chris: Fantastic. Well then, I'm going to put a stop to the recording now unless you have any last things you want to say to us, Francisco?

Francisco: No.

Chris: Okay.