

Analyzing Physics Majors' Specialization Low Interest Using Social Cognitive Career Theory

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As students pursue a bachelor's degree in physics, they may ponder over which area to specialize in, such as theory, computation, or experiment. Often students develop preferences and dislikes, but it's unclear when this preference solidifies during their undergraduate experiences. To better understand, we interviewed eighteen physics majors at different stages of their degrees regarding their interest in theory, computation, and experimental methods. Out of the eighteen students, we analyzed only nine students who rated computation and theory the lowest. Our analysis did not include interest in the experiment because the ratings were less negative. We used Social Cognitive Career Theory (SCCT) and Lucidchart to analyze students' responses and create individual graphical representations of the influences for each student. Through this, we uncovered how various factors such as learning experiences, self-efficacy, and outcome expectations influenced their low interest in a particular method. We found that lack of knowledge and experience is often the main reason why self-efficacy was lower. Students' lack of interest is also influenced by negative outcome expectations (e.g., math-intensive and a bad work-life balance) more than other SCCT factors. Our findings could help physics departments and educators identify positive and negative factors that could lead to a more motivating and inclusive physics curriculum.

I. INTRODUCTION

In order to provide students with the best possible education, physics departments should prioritize creating a learning environment that is engaging and challenging and also emphasizes the importance of different method specializations such as theory, computation, and experimental skills. By doing so, students can develop a deeper interest in these areas and gain a better understanding of their future goals and their career options. Students' actual experiences as physics majors may fall short of this goal. For example, some physics majors may not have access to much computational coursework [1], and most will get far more practice with theoretical problem-solving than with hands-on experimental work.

According to statistics from the American Institute of Physics [2], 50 % of physics bachelor's degree recipients who seek jobs in the private sector are working in computing and engineering-related jobs. For those who pursued graduate school, about 50% used experimental methods for their research, 37% did theoretical work, and 10% used observational and other methods [3]. However, there isn't much research on what factors influence these career choices. Additionally, substantial prior work has focused on how students' physics identity [4] and out-of-class learning experiences in high school affect their decision to study physics in college [5, 6]. Other work has studied interest in physics and long-term retention [7].

The focus of this study is to gain insight into the factors that affect the career transition of physics graduates. Due to a need for brevity, we focus on only negative interest formation. Understanding students' low interest is important so we can address the underlying causes and create more inclusive environments that encourage diverse career exploration. The main research question addressed in this study is: *What factors and experiences contribute to physics majors developing a low interest in two particular method specializations (theory and computation) in physics?* By exploring this topic, we hope to better understand the decision-making processes of physics students and identify strategies that support rather than hinder their future career paths.

II. BACKGROUND

The theoretical framework for this study is based on Social Cognitive Career Theory (SCCT), which reveals different aspects of career and interest development [8, 9]. Figure 1 shows the SCCT map, which consists of self-efficacy, outcome expectations, proximal environment influences, interest, and learning experiences. In SCCT, learning experiences are any learning opportunity that may have had an influence, self-efficacy refers to belief in one's abilities, outcome expectations are the perceived consequences of career choices, proximal environmental influences are external factors beyond the learning experiences, and interest reflects the degree of positive or negative sentiment and an intent to pursue in the future. These are the important blocks of the SCCT map that differ the most between students. We have also included the

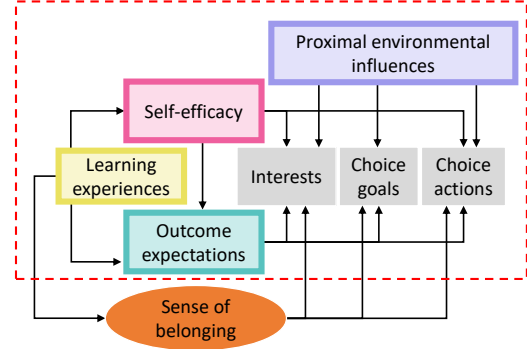


FIG. 1. Map of interrelated constructs within Social Cognitive Career Theory and an additional sense of belonging construct.

influential factor of a sense of belonging in our SCCT map [10–12]. Sense of belonging refers to individuals feeling a sense of fitting in and connection within a specific community. This feeling of belonging can drive motivation, influence the formation of interests, and ultimately impact their chosen career path.

When considering the development of interest in certain method specializations in physics, it is important to explore what factors and experiences may contribute to this process. SCCT posits that interests are shaped by self-efficacy and outcome expectations that are influenced by learning experiences. It is assumed that students gravitate towards fields and topics for which they have higher self-efficacy. Having poor performance in previous courses could lead to lower self-efficacy. On the other hand, outcome expectations are what a student expects work or life will be like as a consequence of working in a particular field or with a specific method specialization. SCCT assumes that people will engage in activities that they expect to be rewarding. One example of a negative outcome expectation is that a particular career has lots of pressure and a poor balance between work and life. Proximal environmental influences refer to the contextual variables that influence students' interests, such as family or peer support can impact a student's interest.

Finally, following along the map, choice goals and choice actions refer to an intent or action to take part in activities related to the method of interest and achieve a certain level of success. In our study about low interests, a choice goal or choice action could be avoiding a particular method. Through the exploration of this topic, the study hopes to gain insight into the low-interest formation experienced by physics undergraduate students.

III. METHODOLOGY

Our study involved semi-structured interviews with undergraduate physics students in the Summer 2022 and Fall 2022. We recruited participants for our study through various channels, including a student-organized Discord server for physics majors, an email through the physics department, and visit-

ing a course for first-year physics majors. All participants were from the same large private research university in the United States, which has about 200 undergraduate physics majors. In total, we interviewed eighteen physics students who were at different stages of their studies. Out of the 18 physics students, we chose to analyze the five lowest ratings for computation and the five lowest ratings for theory, which included nine distinct students. Since the overall rating of the experimental method was high, we did not include it in our analysis. Of the 9 participants, 4 described their gender as “man,” 4 as “non-binary,” and 1 as “woman”. Regarding race and/or ethnicity, 7 described themselves as “White”, 1 as “Latino”, and 1 as “Asian”. Finally, 4 were in their fourth year, 3 in their third year, and 2 in their first year. Participation incentives were offered in the form of a \$15 gift card. During these interviews, the interviewer started by asking the students to explain each method to ensure that they fully grasped the concepts and provided clarifications as necessary. Then, the interviewer directly asked students to rate their level of interest in each method on a scale of 0 to 10, with 0 indicating no interest at all and 10 indicating very high interest. Throughout the paper, we use a shorthand notation to indicate interest levels, such as (T-3) to mean a theory interest rating of 3 or (C-5) to mean a computation interest rating of 5. We delved deeper by asking follow-up questions tied to SCCT factors to uncover the various influences on their level of interest. Each interview was recorded, transcribed using Otter.ai, and transcription errors were corrected prior to analysis. To investigate the formation of student’s interests, we were inspired by the phenomenography method [13, 14] to understand the variation in experiences that led to a low interest in theory or computation. The limited sample size of our study limits our ability to reach saturation in data collection and data analysis. First, for each student, we created an individual diagram of each student’s influences using Lucidchart [15] (see Fig. 2-a). Each node in the diagram was a

short quotation or summary about factors that influenced their interest, and links were based on causal connections in the transcript. After creating 10 separate maps, we coded each student’s statements into SCCT categories such as learning experiences, self-efficacy, outcome expectations, as well as a sense of belonging (priori coding). Then, we merged individual maps by combining similar quotes and created one comprehensive map for theoretical interest and one for computational interest (see Fig. 2-b). This allowed us to see the variation across students’ experiences and highlighted similar and contrasting factors that impacted their interest formation. Finally, for each method, emergent subcategories (inductive coding) were identified within the SCCT and sense of belonging constructs (see Fig. 2-c).

IV. RESULTS

A. Interest Levels

We characterized interest based on students’ numerical ratings and their qualitative comments. Based on numerical ratings, students in our study had a more negative perception of theory (T) (ratings: 1,2,2,2,4; Av. = 2.2) compared to the computation (C) (ratings: 3,3,5,5,5; Av. = 4.2). For the other participants who were not analyzed here, the average rating was 7.4 for theory (ranging from 6-10) and 7.0 for computation (ranging from 5-10). The average for experimental work among 18 students was 8 (ranging from 5-10).

Students’ interest was also indicated by their language when describing a particular method. Some students expressed strong negative emotions and language when discussing their lack of interest in theory. For example, Skyler, who rated theory a 2 (T-2), stated, “I hated the materials. It wasn’t necessarily a negative class experience. I just did not enjoy the material in the slightest... Just cringe. The professors are all crazy, and I’m blanking on every class I’ve ever taken. Modern was garbage.” Skyler continued that they had a supportive professor that tried to help them, but they were not paying attention. They said, “I voluntarily excluded myself from theoretical areas and feel dread to get involved in this type of work.” Armond (T-1) also used strongly negative language, describing theory as “miserable,” “class was really just gross,” “data is just basically irrelevant,” and “Astro stuff was horrible”. Other students who rated theory low had less emotional responses, with Sean (T-2) and Wren (T-2) using words such as “a little disappointed,” “not fun,” “not entirely bad,” and “not horrible.”

On the other hand, students who rated computation as their low-interest method used a mix of positive and negative language. For instance, Bert (C-3) expressed that seeing programs run efficiently is really cool, but he doesn’t enjoy coding. He also admitted that he will need to use computation throughout his professional life, but he prefers to limit it as much as possible. Jamie (C-5) thought, “There’s less funkiness in computing, and slightly more funkiness in experiments,” while Moss (C-5) expressed having a love-hate relationship with it since “it has been frustrating working with computational physics,...but useful.”

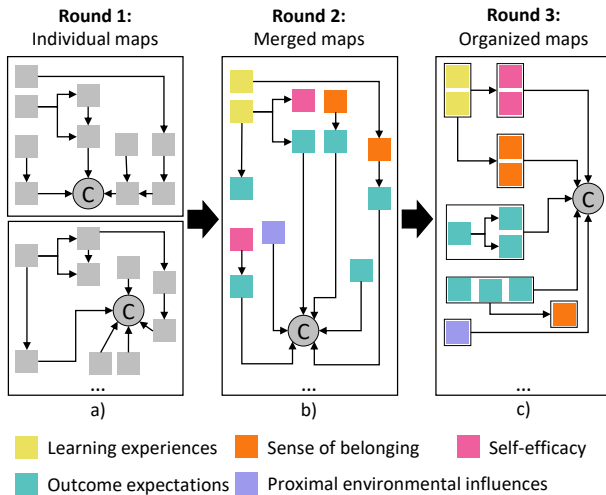


FIG. 2. Data analysis steps. (C) means a computation.

B. Learning Experiences

Within our data, students who were not interested in theory often had negative experiences with theory-related courses, both prior to and during college. Wren's (T-2) low interest in theory was linked to their perception of high school geometry. They said, "Geometry class in high school was a lot of proofs, and I just did all the geometry proofs, and I was like, I don't like doing proofs." Additionally, one student shared his negative research experience as a contributing factor to his low interest. Armond (T-1) had a summer research experience in Astrophysics, which influenced his negative perception of theory. He said, "I didn't really enjoy it. I really liked Astro before that. I was like 'Astro is so cool, I'm going into Astro.' But after I did that project, I completely got turned off by Astro. I was like, 'I don't want to do this ever again.' The data is just basically irrelevant to me. It has no significance... It's just numbers." For Armond, a dislike of theory is coupled with a dislike of astrophysics. We will come back to the influence of irrelevance in the section on outcome expectations.

However, we found that students who rated computation lower often had negative experiences with coding during their research experiences. A few students also shared stories about their experiences with computational courses at various levels of education, from pre-college to BS/MS programs. It is important to note that not all of these learning experiences were necessarily negative or unpleasant. As we delve deeper into the results, we'll examine what specifically made these experiences unpleasant in subsequent subsections.

C. Self-efficacy

When students were asked about their confidence in a method specialization that didn't interest them, they often reported feeling capable to some extent. For example, Armond (T-1 & C-3) and Sean (T-2) felt confident in their understanding of physics. Negative perceptions of theory work, as seen in Armond's case, could be linked to his negative experiences with computation, but he thought, "If I'm given the right tools, I could probably do it. I might be bored." Kennedy (T-4) and Jamie (C-5), both rising 1st-year students, shared a similar sentiment that they were to some extent confident but also acknowledged that they still had more to learn. For example, Kennedy said, "I think we'll get more confident over time as I understand more physics laws and stuff like that and be able to apply them to new solutions." Dave (C-5), who became a physics major because he wanted a better understanding of the world, said, "If I actually tried, it could probably be pretty achievable. I would just learn how to code and then learn how to make predictive models." However, for Bert, the mathematical process and coding were a particular challenge, and his confidence level varied depending on the complexity of the process. He said, "I had no clue how to go about coding, how to learn about it, how to do it, how it could improve, how I code, or what I could see that was wrong... Very minimally. I don't understand them. In every other STEM category,...I can at least see how I did something

wrong, whereas, for coding, there are no indicators of how your code is wrong. There is, but very minimally. I don't understand them. My impression of coding was I couldn't do this without a teacher, or I didn't have enough motivation to do this without a teacher. Because I tried learning coding on my own at one point, and it just didn't work. Either I just chose the wrong classes or just didn't understand."

A student's self-efficacy in a method specialization can be influenced by pedagogy. For example, Moss (C-5) mentioned feeling more confident in one-on-one teaching situations. However, even in those settings, professors could negatively influence confidence if the student perceives the professor is down-talking or lecturing them.

D. Outcome expectations

Our research identifies three categories of outcome expectations that influence students' interest development: disciplinary ideas, practices, and professional/personal life.

Disciplinary ideas refer to the in-depth content knowledge of a certain type of method specialization in physics. For example, Armond (T-1) who prefers "hands-on work rather than use his brain", had difficulty grasping the micro-scale of the theory. Some students, such as Moss (C-5), had less interest in pursuing theory or computation because they were interested in the immediate translation to real-world applications rather than the acquisition of fundamental skills and knowledge. Sometimes in computation and theory, students may struggle with visualizing their work and not feel a physical connection to it. Sean (T-2) described it as "It can feel like just stringing ideas together" without anything concrete to hold on to. However, there are benefits to using computation in place of physical experimentation. For instance, it can save time and money. Armond (C-3) argued that by allowing the "computer to do the heavy lifting", you just have to give it instructions. This can be challenging, but it can also be more cost-effective than conducting experiments over time.

Practices refer to the outcome expectations subcategory dealing with the day-to-day performance of particular skills or tasks associated with a method specialization. It is common for students to think that both computation and theory are math-intensive methods. Wren (T-2) feels that "theory involves a lot of proof" while Sean (T-2) finds it "unsatisfying to sit and do derivations." Additionally, some students believe that these types of work won't involve collaboration, as Dave (C-5) prefers "interacting with people and seeing the progression of hard work." There is also a negative expectation that theory and computation work won't be hands-on and will involve lots of sitting in front of the computer and lots of coding and formalizing ideas. For example, Wren (T-2) likes having their own thoughts but dislikes having to mathematically formalize them. Additionally, some students perceive working in theory to be "time-consuming," with "lots of Zoom calls," "long hours [of] reading," "lots of literature searching and lots of generative writing," "understanding textbooks," "us-

ing a lot of chalkboards,” and “justifying each [idea].” For instance, Kennedy avoids theory because she “likes to figure things out quickly.”

Professional and personal life is an outcome expectations subcategory that addresses the overall lifestyle associated with a method rather than perceptions of the day-to-day work. As students think about their future careers, they consider their lifestyle expectations and how they can find a balance between their professional work and personal life. Many want to prioritize their mental well-being and create a healthy work-life balance. Kennedy (T-4), for example, hopes to have time for “social life and my other hobbies” while avoiding the stress of constantly thinking about work. While Moss (C-5) had a love-hate relationship with computation (i.e., frustrating but useful), they thought computational work would support their desired lifestyle, which is working remotely or traveling for conferences. They said, “When you’re a researcher, that’s essentially what I want to be, and when [you are] doing research, hopefully it would require me to travel sometimes.” Theoretical work was usually linked to being a professor, working with students, and having an office in a physics department.

E. Proximal environment influences

Some students’ interests in computation may be influenced positively or negatively by environmental factors such as family or friends in the field. Moss (C-5), for example, was initially pressured by their father to pursue computer science, but the pressure actually deterred them from it as a teenager. However, as students’ interests can evolve over time, encouragement and support from loved ones can have a significant impact in reshaping their future career paths. In addition to being a role model for their little brother at home, Moss explained how they work in a nursing home and have opportunities to explain their research to “old folks” who are “completely impressed and proud”. Besides family and friends, Armond (C-3) and Dave (C-5) found it challenging to interact with other students during the COVID-19 pandemic, which lowered their interest in courses during that time.

F. Sense of belonging

Sense of belonging is an important element that is not part of the SCCT framework and focuses on the social connections of students within their community. Creating a sense of connectedness and being recognized by others through the different learning experiences can enhance interest in a particular method. Moss (C-5) shared their experience of feeling out of place in the computational courses, where they rarely felt encouraged or congratulated. Moss also noticed an unequal representation of genders in computation classes, which made them feel like they didn’t belong in those spaces. However, they found more support in their research setting, where their peers and mentor provided them with more moral

support, leading to a more positive experience with computational physics. Moss said once they did work, their peers were “like, Oh, my God, congrats, good job! They all send a little reaction, like a cute congratulations emoji, and that kind of stuff is important.” On the other hand, lack of encouragement or negative experiences led to a lack of sense of belonging, as seen in Sean’s case, where he felt excluded in theory classes because his peers didn’t take him seriously. In addition, Sean (T-2) also stated that he had “to prove myself to the professors by the way that I look.” Sean did not elaborate on this statement.

V. CONCLUSION

The findings on students’ perceptions of theory and computation have important implications. The origins of students’ negative views can highlight specific areas where the curriculum could be enhanced. Despite frustration with coding and debugging, students with lower interest still recognized the importance of computational work in their future careers, emphasizing the practicality of integrating computational skills into the physics curriculum. On the other hand, students’ perceptions of theory as irrelevant and not useful led to negative outcome expectations. To address this gap, theory courses could incorporate more real-world applications and reflect the impactful areas of contemporary physics research. However, additional computational training may be needed to help students become more efficient at coding and debugging, which may make the experience less frustrating. Students perceived broad career options involving computational work, but that theoretical work was associated with being a professor. This may be partly correct and suggests that departments need to address the relevance of theoretical coursework to non-academic careers. Additionally, students need opportunities for recognition to build a sense of belonging with respect to different aspects of physics. Courses involving collaboration, regular formative feedback with encouragement, and projects may be more likely to support a sense of belonging.

By conducting further research, we hope to identify areas where students require additional resources. Our long-term goal is to create assessment tools that gather broader data, which can be used by the physics departments to identify sources of negative interests and whether some students lack access to positive experiences. Using this information, departments could design targeted strategies to improve support for students in their academic and professional journeys. Ultimately, we emphasize the importance of aligning curriculum, career guidance, and instructional approaches to enhance students’ interest and readiness for a wide range of careers in physics.

VI. ACKNOWLEDGMENTS

This work was supported by the National Science Foundation under Grant No. 1846321.

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