Analysis of Physics Students' Subfield Career Decision-Making Using Social Cognitive Career Theory

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The ways in which physics majors make career decisions is a critical, yet understudied, aspect of the undergraduate experience. Such decisions are important to students, physics departments, and administrators. In this project, we specifically examine how students develop interests and intent to pursue specific subfields of physics by interviewing 13 physics majors from all years of study. The interviews examined factors that led students to choose their most preferred and least preferred subfields. Interviews leveraged the framework of Social Cognitive Career Theory, a model that describes how several constructs such as self-efficacy, learning experiences, and outcome expectations relate to decision-making. Findings highlight the differences in decision-making between upper-division students and beginning students. For instance, we see how popular culture and popular science provide an initial learning experience about certain subfields, such as astronomy and astrophysics, which strongly affect beginning students' perceptions of that subfield. Initial exposure to biology and chemistry in high school or early undergraduate classes often negatively affected students' interests in fields like biophysics or chemical physics. Data also suggests a splitting between students with respect to their outcome expectations of a desirable career in science. While some students prioritize using science to help people, others prioritize discovery of new knowledge through science, and some are in between. Students in both groups form perceptions about subfields that do not align with their identities and hence make decisions based on these perceptions. For instance, a student who prioritizes helping others through science may be quick to reject astrophysics as a subfield choice as they do not think that astrophysics can help people enough. (Supported by NSF DGE-1846321 and REU-1757477)

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I. INTRODUCTION

A degree in physics lends itself to a multitude of diverse career paths and subfields (e.g., biophysics, nuclear physics, or optical physics). After graduation, 48% of physics graduates find employment while the other 47% pursue graduate school [1]. Whether they pursue graduate education or a job, each of these students has to decide which subfields of physics they wish to pursue or avoid in their career.

Investigating how students make such important career-related decisions is important for a variety of reasons, including the promotion of diversity and inclusion in physics. The AIP TEAM-UP report recommends fostering career awareness and educating students about the positive impacts of physics careers as ways to supporting African-American students in physics [2]. Additionally, some subfields, such as astrophysics and astronomy have significantly higher participation of women (35-40% at the BS, MS, and PhD levels) [3], which raises interesting questions about why these differences arise. Yet this topic is largely understudied, Docktor and Mestre's 2014 review of PER does not include a discussion of college to career transitions [4], though work has been done on career decision-making of undergraduates regarding their interest in physics [5] and astronomy [6]. Recently, Cardona *et al.* described how physics majors formed interests and an intent to pursue particular method specializations (i.e., theoretical, computational, or experimental) [7]. This paper extends Cardona *et al.*'s work to analyze how physics majors develop interests in particular subfields. Our research is driven by the following questions:

- RQ1 - What factors cause students to develop positive interests in their most preferred subfields of physics?
- RQ2 - What factors cause students to develop negative interests and avoid other subfields of physics?

To answer these questions, we conducted and analyzed interviews based on the theoretical framework of Social Cognitive Career Theory. Through this, we hoped to gather insight into students' subfield decision-making and ultimately shed light on the complex process of career decision-making for a physics major.

II. BACKGROUND

Figure 1 shows a simplified model of Social Cognitive Career Theory (SCCT), which displays the relationship between learning experiences, outcome expectations, self-efficacy, interests, and choice behaviors [8–10].

Within SCCT, learning experiences refer to any event undergone by the student in which they learn something about the decision at hand. For instance, a class in astronomy could act as a first learning experience for a student wishing to pursue astrophysics. Or a research experience in biophysics could teach a student about current research methods in that subfield. Self-efficacy refers to a students' perceived ability to succeed at a task or in a career [11]. For instance, a student could feel highly confident working in an undergraduate optical physics class and wish to pursue optics as a career. Outcome expectations refer to students' perceptions of what a career would look like if they were to pursue it. For example, a student might avoid a job in quantum physics if they perceive the work in quantum as too hands-off and theoretical. Because outcome expectations are based on the students' prior knowledge, it may or may not match actual experiences of someone in the field. All of these constructs directly influence the development of interest in a particular career path. For the sake of this paper and this research, we aim to analyze how the first three main constructs (learning experiences, self-efficacy, and outcome expectations) influence interest development in particular subfields of physics.

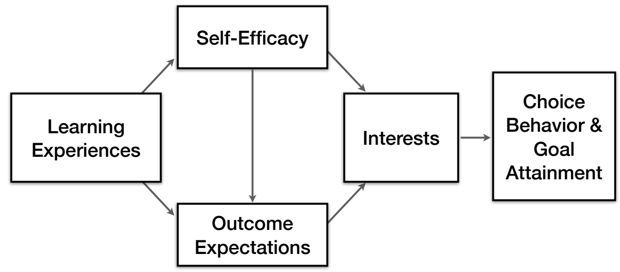

FIG. 1. Simplified version of the Social Cognitive Career Theory model of students' career decision-making. Adapted from R. W. Lent, S. D. Brown, and G. Hackett (1994) [8].

The college to career transition for physicists is largely understudied in PER. Prior research exists on students' transition from high school to college [5, 12]. For example, Mau *et al.* used SCCT to assess how students form career interests in STEM and how they decide what STEM major to pursue in college [12]. SCCT has also been used to examine how students form interests in particular methods specializations in physics (e.g., experiment or theory) [7]. Similarly, Hazari *et al.* used a physics identity framework to analyze how students form perceptions of physics based on high school physics classes, as well as how these perceptions affect their career choices in physics [5].

III. METHODS

We developed an interview protocol with questions based on each SCCT construct. The goal was to ask about the subfields students are interested in, as well as the subfields they do not have an interest in. Two example questions based on SCCT are provided below:

- Do you feel confident in your ability to do work related to this type of physics? [Self Efficacy]
- What aspects of this type of physics make you not want to pursue a career in it? [Outcome Expectations]

Additionally, as a part of the interview processes, students were provided with a card ranking activity in which they were given a series of subfield names on printed cards. Students were asked to rank them from least favorite to most favorite. The final protocol underwent an intensive review process between many members of our research group. The interview protocol was also refined through the first 5 interviews. The last 8 were performed with a final protocol.

Students from each year of undergraduate study (3 in year 1, 2 in year 2, 3 in year 3, 5 in year 4) were recruited through social media platforms dedicated to physics majors. As an incentive, students were given a $10 Amazon gift card for their time. In total, 13 students were interviewed. Through a demographic survey given with the interview, students provided relevant demographic information such as age, gender identity, ethnicity, and year of study. All participants were white, non-international physics majors enrolled at the same university. In our data, 7 students identified as men, 2 as women, 2 as androgyne, 1 as agender, and 1 as a trans man.

Interviews were performed in person and recorded using Zoom. Audio files were automatically transcribed and then typos and punctuation were manually edited. Transcripts were qualitatively coded using Dedoose [13]. The first round of coding used a priori codes for each SCCT construct (see Figure 1). For example, one student said, "When I toured the Zygo factory, I really didn't like the day to day," which was coded as "Learning Experiences" and "Outcome Expectations." We also applied "initial codes" to capture more of the nuance and detail within that SCCT construct [14]. Coming back to the previous example, the "Learning experience" was given the initial code "Factory Tour" while the "outcome expectation" was also coded as "wouldn't enjoy day-to-day" [14]. Approximately 200 initial descriptive codes were applied. Here we report on a series of 5 themes that arose from the data.

IV. RESULTS

A. Theme 1: Subfield Unfamiliarity

All students interviewed expressed some degree of unfamiliarity with one or more physics subfields. From the perspective of SCCT, these students lacked learning experiences that introduced them to certain subfields. Generally this led to low interest and reduced choice behavior. For example, one first year student expressed a partial uncertainty in what exactly biophysics is:

> *I think there was like a presentation in [an intro class], someone doing biophysics and they kind of explained it a little.*

Students in the latter years were also unfamiliar with an array of physics subfields. For example, this fourth year student did not know biophysics until late in their undergraduate career. Due to this unfamiliarity, their choices were limited to only the select few subfields that they knew about. Thus, they made a decision regarding their preferred subfield without being able to weigh all their options:

> *By the time I even heard about biophysics I had kind of made up my mind. A lot of the subfields of physics, I didn't even know where things were until after I came here and I started doing research in other fields.*

Interviews revealed that there were certain subfields of physics that students consistently did not recognize. Students in their earlier years of study were more likely to be overwhelmed by the number of subfields (14 were provided in the ranking exercise). Often students resorted to guessing what certain subfields were based on their. For example, the following first year student attempted to figure out what geophysics is about:

> *Oh god. I do not know what geophysics is. I'm just going to hope it has something to do with...earthquakes.*

B. Theme 2: High School Learning Experiences Affect Collegiate Decision-Making

Another theme arose specifically regarding students' perceptions of chemical physics and biophysics. When students were presented with these subfields during the ranking portion of the interview, they would frequently link the prefix of the subfield (e.g., the 'bio' in biophysics) to an outcome expectation they had formed through an introductory class they had taken in high school or college (e.g., AP biology). When the following student was asked about biophysics, which they ranked as their least favorite subfield, they said:

> *I've taken bio classes in high school, like before coming here and it doesn't make any sense to me. It doesn't even interest me to learn more.*

For some students, this led to negative opinions about certain subfields. For example, the following student, who had a poor experience with chemistry in high school, stated:

> *It's all a lot of rote memorization. Like in physics there are patterns and you can learn about how stuff works.*

Because of this belief about chemistry, the student does not see chemical physics as an option. These findings indicate that early learning experiences cause students to view the choice between disciplines (e.g., physics, bio, chem...etc.) as "all or nothing," which could stifle participation in interdisciplinary fields.

C. Theme 3: Popular Science Limits Subfield Exposure and Creates Unrealistic Outcome Expectations

Physics and physicists are portrayed in both popular science news coverage as well as fictional stories and shows (e.g., The Big Bang Theory). However, popular science disproportionately represents scientific results from only a few subfields such as astronomy, astrophysics, and quantum physics. Due to this, broader perceptions of physics are often only informed by representations of subfields that receive the most attention in popular culture. Students in high school or earlier therefore may have a limited or distorted view of what it means to "do physics."

In the context of SCCT, popular science therefore acts as a first learning experience for many students, but can create misguided outcome expectations about the subfields those learning experiences pertained to.

For instance, five students identified astrophysics or astronomy as their most preferred subfields. All 5 of these students cited popular culture as an influence on the development of their interests. For example, one third year student discussed how popular science gave them an avenue to study the physical world:

> *I mean, so learning about space through, like popular science, I absolutely adore it, it's loads of fun. I don't have to worry so much about equations. I just get to enjoy learning about how things roughly happen.*

The fact that popular science outlets most commonly communicate information about only a few physics subfields may contribute to our findings in Theme 1. Through overexposure to the big subfields of physics (e.g., astrophysics, quantum, atomic physics...etc.) students can perhaps miss out on the many other subfields that do not receive the same, or any, air time (e.g., biophysics).

D. Theme 4: College Undoes the Outcome Expectations Formed by Popular Culture

When considering a college major, students' learning experiences in high school and popular culture often fostered positive outcome expectations about pursuing physics or astronomy. However, we found that college learning experiences could sometimes significantly change students' outcome expectations about what work in a particular subfield of physics would be like. Indeed, several students described a decreased interest certain subfields that they thought they would enjoy once they had gained a new, and perhaps more accurate, picture of the discipline.

The following third year student had a positive set of outcome expectations with regard to astronomy growing up. But for this student, taking courses in astronomy and astrophysics changed these outcome expectations enough to deter them from the field:

> *Everyone grows up with space posters on their wall, or the stories you're told like sci-fi fantasy stuff. I grew up like actually looking at the planets and like looking at stars and stuff. And I was like: 'I like physics, I know math, I can study that!'. Then I get to college, and take my first astronomy class, and I hated it.*

Their reasons for a change in interest primarily linked to a change in outcome expectations. During these college level astronomy classes, they learned from astrophysicists what their day-to-day work entails. After learning the details of daily work as an astrophysicist, this student recalled:

> *All I'm hearing is 'I sat at a computer and I looked at data from a telescope'. Oh, man, you don't even get to go to the telescope. That sucks.*

These statements indicate that the typical early exposure to astronomy via popular science channels may be helpful for highlighting the big ideas of the field, but may not be as effective at introducing students to the day-to-day work of scientists.

E. Theme 5: Traditional vs. Altruistic Science Identity and Outcome Expectation Formation

Some students' outcome expectations more directly related to their personal values and science identity. While some students emphasized the importance of helping people through science in their work (altruistic science identity), others were motivated by love of discovery and scientific knowledge for its own sake (traditional science identity). The emergence of different science identities from our data is similar to the science identity framework provided by Carlone and Johnson [15], who also placed scientists' identities along a spectrum ranging from altruistic to traditional.

Altruistic Science Identity: Students that we classified as belonging to the altruistic science identity group often had outcome expectations that regarded "traditional" subfields of physics as overly focused on science and not helpful to people. In our data three students fit into this identity. For example, one student described straying away from a subfield they once had a positive perception of because they did not believe it would allow them to help people as effectively as their preferred subfield of medical physics:

> *I feel like astrophysics lacks that helping people aspect, which is why I don't have interest in it.*

Students in the altruistic science identity category saw science as a tool to help others. When one student was asked what their outcome expectations were of the subfield they want to pursue, they stated:

> *I want to make a difference, whatever it is that I'm doing, I want it to make a difference for people.*

Traditional Science Identity: Students who made statements classified as being part of the traditional science identity split into two groups: those who focused on the positive aspects of discovery and those who focused on their ambivalence toward science as an avenue for helping people. This identity applied to seven of the students in our data set.

As an example of a student in the discovery focused category, one individual described having a strong interest for learning about anything science related:

> *I really like learning about new fields. I like talking to my friends about their research. I like learning about the applications of the field because it's physics, you know, I just love physics.*

On the other hand, another student emphasized that they did want to work with people. When asked why this student had ranked physics education so low on the card sorting activity, they said:

> *...that's kind of why education is so far down there. I just don't like dealing with people.*

Mixed Science Identity: While some students had strong interests that aligned with either the altruistic or traditional science identities, three students represented a blend of both. They expressed approximately equal interest in both helping people as well as loving science for the sake of science. For example, this student had career goals that involved both loving science and helping people:

> *So one of them that I've wanted since I was little is to work for NASA or be a researcher at NASA or ISA, or work for a space agency. Then I figured out that I really like helping people and teaching. I've been a TA and LA and I find those jobs immensely rewarding.*

V. DISCUSSION AND CONCLUSION

Subfield unfamiliarity showed that if students have little awareness of the diverse subfields of physics, they may pursue fewer options for elective courses or for research opportunities, which could limit growth of physics programs. For the student, their limited awareness could lead to fewer interests and more limited choice behavior. By laying out the factors that students are taking into account when choosing physics and subsequent specialties within physics, we can see areas where departments could do a better job of informing students about the realities of doing physics and the many opportunities within the discipline. This has the potential to help bring a more diverse set of students into physics.

Our observation about negative high school and introductory learning experiences in biology and chemistry indicates they may predispose students to avoid particular interdisciplinary subfields (e.g., biophysics or chemical physics). As an education system, being able to consistently provide good science education experiences is important for fostering an openness to interdisciplinary research. Yet, this data suggests a perception of a sharp divide between physics and the other major science disciplines, something that could contribute to lower diversity among physics majors as well. For instance, in 2019 63% of biological sciences Bachelor's degrees went to women [16]. Degree programs that show interdisciplinary connections may support a more inclusive physics community.

Not only are students entering college with inaccurate outcome expectations, they are making decisions with inaccurate outcome expectations. Physics students often are not provided with authentic experiences of doing science until the later years of an undergraduate program. Thus, there may be a need for more early encounters where students can do science, not just be exposed to the big ideas of science. Additionally, through overexposure to particular subfields of physics (e.g., astrophysics, particle physics) students may overlook other subfields that don't receive the same air time. Presenting physics as a field with diverse options could improve diversity and interest.

Traditional identity, as the name suggests, is often seen as the default. Additional research in students' attitudes and perceptions about the skills and nature of physics supports this finding. Research from Leak *et al.* identifies some of the common attitudes and perceptions students have as to what it is like to be a physicist, as well as what skills are important to physics [17, 18]. Leak *et al.* asked: What do students emphasize when asked to describe physics to a high school student considering majoring in physics? It was found that some of the emphasized details were things like "learn how the universe works," "learn how to learn," " have a passion for physics," and "gain flexible skill-sets" [17, 18]. All of these focus on physics being about ideas rather than applications that help people and contribute to society. Physics programs offer plenty of ways for students of the traditional identity to satisfy their curiosity and thirst for knowledge. The altruistic identity is often left out as students see the only way to help others as through teaching (i.e. LA, TA, and SI jobs). Students in this category do not have as many options provided that will satisfy their interests.

The main limitation of this project is that data was solely collected from one physics program. Additionally, the sample had minimal racial/ethnic diversity and small sample sizes in any particular year of study (3-5 per year). Our sample was also limited by the range of interests displayed by students, most participants favored astrophysics, or were interested in physics education research which left the remaining subfields unstudied. For future work, interviewing students from many different subfield choices would further improve our picture of what subfield decision-making is like for all students. This work is supported by NSF Award DGE-1846321 and REU-1757477

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