

Exploring subfield interest development in undergraduate physics students through social cognitive career theory

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(Received 16 July 2024; accepted 8 July 2025; published 21 July 2025)

This study investigates how undergraduate physics majors develop an interest in specific subfields. We examine interest formation through the lens of social cognitive career theory (SCCT) using four SCCT constructs: learning experiences, self-efficacy, outcome expectations, and proximal environmental influences. We conducted 27 interviews with physics majors across multiple years of study between 2020 and 2022. Our first research question used SCCT constructs to provide detailed insights into factors affecting interest formation in various subfields of physics. We identified many factors that positively impacted students' interests, such as positive learning experiences (e.g., coursework, experimental projects, extracurricular clubs, and self-directed learning), high self-efficacy (e.g., encourages seeking new opportunities and developing positive outlooks on future careers), outcome expectations (e.g., wanting a stable job and work-life balance), and proximal environmental factors (e.g., influences from the COVID-19 pandemic and institutional factors). Our second research question involves a comparison between the two subfields that had the largest number of students expressing interest, which were astronomy and astrophysics and biomedical physics. Exposure to astronomy occurred prior to college, while biomedical physics was usually encountered during college. Additionally, outcome expectations related to biomedical physics revolved around practical or clinical applications that helped people, while astronomy was linked to fundamental, curiosity-driven research. By understanding these factors that affect how students develop their interests, we hope to provide valuable insights to physics departments and career guidance professionals who want to better support physics majors' transitions beyond the bachelor's degree.

DOI: [10.1103/cgcb-4k6z](https://doi.org/10.1103/cgcb-4k6z)

I. INTRODUCTION

Physics graduates pursue diverse career paths: Approximately 50% of physics bachelor's graduates enter employment, 30% pursue graduate studies in physics or astronomy, and 16% pursue graduate studies in other fields (e.g., engineering) [1]. Condensed matter physics is the most common subfield chosen by physics Ph.D.'s, with around 20% of doctoral candidates specializing in it in the classes of 2019 and 2020 [2]. The same AIP report also stated that around 14% of physics Ph.D. candidates specialize in astronomy, astrophysics, or cosmology, while 8% specialize in biophysics. However, factors influencing subfield interest and its impact on employment remain unclear. This further underscores the need for better characterization of career decision-making processes.

As the Effective Practices for Physics Programs (EP3) [3] and the TEAM-UP report [4] both emphasize, there is a need for improved support and guidance for physics students, as well as the development of effective interventions to support career preparation and decision making.

Compared to physics programs, engineering and computer science programs typically have stronger connections to specific job opportunities and particular industries, which is often facilitated through internship programs, industry-sponsored senior design projects, advisory boards, and accreditation boards. On the other hand, undergraduate physics programs often lack industry connections and career preparation resources found in engineering and computer science, leading to a disparity between program offerings and students' career goals.

Our study aims to identify factors that contribute to positive and negative subfield interests and subsequent career decisions. We hope to provide useful insights for physics departments that want to redesign their physics program for career preparation. Research on subfield decision making is also relevant for efforts to create inclusive educational opportunities and understand gender

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differences in physics. These efforts are particularly important in disciplines that want to attract students from a broad range of demographic and disciplinary backgrounds [5]. Importantly, our study does not seek to extend or validate the SCCT model; instead, it applies the SCCT model to better understand how career interests form in physics subfields.

Our study is guided by the following questions:

- RQ1: What factors contribute to students developing interests in specific subfields of physics?
- RQ2: Do interest formation processes differ between different physics subfields, such as biomedical physics and astrophysics?

II. BACKGROUND

A. Theoretical framework

Our data collection and analysis was designed using social cognitive career theory (SCCT), which describes how psychological characteristics and other factors impact individuals' career interests and attainment [6,7]. For instance, quantitative studies using SCCT surveys have investigated interest formation in math [8], computing [9], music education [10], and engineering [11,12]. There are also qualitative studies using interviews in fields such as undergraduate computer science [13]. Figure 1 illustrates the SCCT model of how individuals making career-related decisions and choices. Our primary focus is on the colorful (nongray) constructs depicted in Fig. 1 (learning experiences, self-efficacy, outcome expectations, interest, and proximal environmental influences), which were most relevant to our student interviews and college experiences.

According to the SCCT framework, students' decisions are affected by their precollege experiences and background influences as well as personal factors such as gender, race or ethnicity, disability status, and socioeconomic status. Early exposure through precollege experiences, such as high school courses and extracurricular activities, allows students to explore different areas and develop preferences. They may also more directly impact students' ability to achieve their goals. The construct of

learning experiences includes all educational activities and opportunities that can affect a student's knowledge, skills, understanding, attitudes, and beliefs related to a particular career path. In SCCT, learning experiences shape a student's self-efficacy, outcome expectations, and interests. These experiences inform how students perceive their own capabilities and the potential outcomes of pursuing certain activities (e.g., physics subfield choices). Over time, learning experiences contribute to the formation of personal interests and beliefs about career possibilities.

In contrast, Lent *et al.* [6] defined proximal environmental influences (PEI) as situational factors that typically affect a student's decision making at a specific point in time, such as financial constraints, job prospects, and familial expectations. For example, a student might be drawn to particle physics due to positive learning experiences but choose not to pursue it as a career because of limited job opportunities in their desired geographic region (a proximal influence). These influences function as external pressures rather than internal beliefs about ability. Lent *et al.* suggest that while learning experiences reinforce or challenge self-efficacy through academic learning experiences and achievements, PEI instead bypasses self-perception and affects the feasibility of choices based on current environmental factors. Self-efficacy describes a student's belief in their ability to succeed in specific tasks or situations related to their career. Outcome expectations are what people anticipate will happen as a result of performing specific actions, such as pursuing a particular career path. Positive outcome expectations, such as financial rewards, job satisfaction, or career advancement opportunities, can serve as powerful motivators that encourage students to pursue and persist in their chosen careers. Conversely, negative outcome expectations, such as a poor work-life balance, may demotivate students from pursuing a particular career path. In the SCCT framework, interests give rise to goals and actions.

B. Prior work on career interest formation

Many studies, both qualitative and quantitative, have been done on physics career interest and decisions. Many of these studies are focused on what leads students to become physics majors (e.g., [14,15]), to stay in physics and finish a bachelor's degree (e.g., [16]), and continue in physics or astronomy in their career or graduate school (e.g., [17]). Many studies examine how physics career interests and decisions differ for particular groups of students, most often women, with the hope of creating a more inclusive and supportive physics education system. Much of this research has focused on linking psychosocial constructs such as physics identity, self-efficacy, sense of belonging, motivation, and career expectations to particular choices or to persistence in physics.

At the undergraduate level, students are more likely to choose physics when they have a higher physics identity

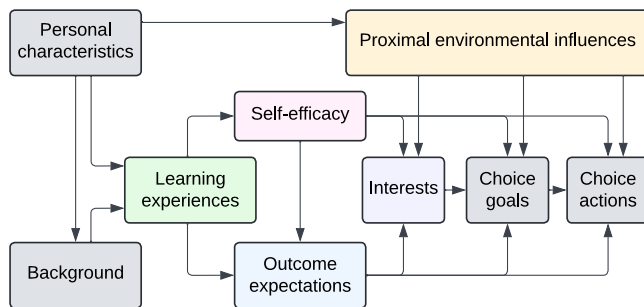


FIG. 1. Map of interrelated constructs within social cognitive career theory. The focus of this study is the nongray constructs depicted in the figure.

and be recognized as a physics person by others [14]. Choosing physics is also associated with strong intrinsic interest in physics [18] and a desire to do research and make a theoretical contribution to science [19]. Physics majors tend to be more open minded about possible future careers [19], which could link to flexible career options. Students who place more emphasis on the utility of the degree may be more motivated to pivot to engineering [16,19]. Finally, physics majors show lower levels of social activism compared to the general college student [19].

At the graduate level, much of the focus has been on why some students (women in particular) stay on an academic track that could lead toward an eventual faculty position and why other students pursue alternative paths. Positive factors for pursuing an academic track include aligning a job with deeply held interests, academic freedom to pursue research, and job security (if one can obtain tenure) [20]. However, reasons for leaving the academic track include a desire to have a better quality of life [21] and a desire for a better work-life balance, including time for family [17,22]. Additionally, women are more likely to limit career options because of a partner's job [23], and academic paths with multiple short-duration postdocs are particularly challenging in this regard [20]. Other factors contributing to leaving the academic path include a lack of acknowledgment [24], more frequent gender-based discrimination [20], and peers with poor social skills that made it hard to form study groups [17]. Positive influences supporting staying were identity-based affinity groups and professional networks [24] and peer study groups [25]. Early involvement in research also tends to increase sense of belonging in graduate school and support persistence through challenging coursework [26,27]. Graduate students who leave the academic pathway can feel guilt associated with their decision [20]. Similarly, at the undergraduate level, some students perceive that faculty celebrate graduate school more than those who get a job after a bachelor's degree.

All of these studies have focused generally on physics career interests, but have not closely examined any particular subfield. There is some prior research on particular physics subfields, such as astronomy, high school teaching, physics education research, and quantum information science and technology. Many studies point to the role of undergraduate research as supporting more specialized interests in a subfield [28], which also contributes to the search for a research lab in graduate school [27]. Research experiences become a gateway into a research community and a greater sense of belonging [25,26,28].

Astronomy and astrophysics form some of the earliest exposure young people have to physical science. Middle school students have a higher astronomy interest, which decreases through high school [29]. Observing stars as an extracurricular activity was linked to higher astronomy interest late in high school, particularly for women [29]. Yet for graduate students engaging in astronomy research, the

day-to-day work could seem more mundane at a computer analyzing data rather than outside with the stars [22]. Astronomy also possesses subfield-specific stereotypes about how astronomers dress [22].

Physics teaching is another subfield career path that has received significant attention due to a shortage of qualified physics teachers in the United States and in other countries. Although physics majors overall show less interest in social change [19], students with an interest in physics teaching describe it as a meaningful career [30] that can be used to support positive social change [31] and aligns with altruistic motives [32]. Students also describe extrinsic motivations [32], particularly a stable and secure job [30]. Additionally, intrinsic motivations, such as a love for teaching and working with students [32] and a strong love of physics [31] are common among students who pursue physics teaching. Key features in forming this interest are opportunities to teach and work with students [31–33], which also includes learning assistant programs [34]. Physics teaching, like astronomy, is a specialization that sometimes is linked to a specific bachelor's degree or is part of some other structured program designed to recruit and train future teachers. Within these programs, pedagogical courses, especially those that occur early in the program, can be motivating [33]. Even for physics majors not initially interested in teaching, this coursework can encourage students to seriously consider the possibility [32]. Other factors include mentorship and becoming part of a community of teachers [33]. Although most of this literature focuses on educating bachelor's students to become future high school physics teachers, graduate students may see college-level teaching as an attractive alternative path that offers better work-life balance [22].

Research on career paths into physics education research (PER) has revealed that many students discovered PER through an advisor or research talks, but not through coursework [35]. For many students, PER was not discovered until graduate school [35,36]. Students who pursued PER were motivated by a desire to make a direct impact on people rather than a longer-term indirect impact through other forms of research. Students in PER had strong research interests, but many also expressed an enjoyment of teaching [36].

Finally, the growing interest in quantum information science and technology (QIST) has led to studies of interest formation in this interdisciplinary subfield, which has strong overlap with physics. One study showed how an upper-division, project-based lab course could increase quantum career interest [37]. Other studies of QIST interest formation have focused on university students in general [38] or science, technology, engineering, and math students [39] rather than physics majors. Generally, those studies show a low awareness of QIST careers. For many other prominent subfields of physics, there is little research on which students pursue those areas and why.

Our own broader research trajectory has been focused on how physics majors make specific career decisions. Starting in 2020, we have conducted dozens of individual interviews with students majoring in physics to explore their preferred methods in physics (e.g., experimental, computational, or theoretical) [40,41] and interests in various subfields of physics [28,42]. Our long-term goal is to help physics departments prepare students for successful careers.

Interest in specific methods strongly affects students' career paths. The most common private sector jobs are in computing and engineering fields. Over 85% of physics bachelor's graduates who work in computing fields and more than 50% of engineers use programming daily [43]. Interest in experimental work often leads to engineering careers or experimental research in graduate school. Across many of the largest subfields of physics, most Ph.D.'s are experimental [43,44]. Low interest in experimental methods can limit career interests in major physics subfields [41]. In our prior work, we found that students less exposed to experimental work in college have lower self-efficacy and interest in experimental physics careers [40]. However, in terms of outcome expectations, many students saw computation as essential for future careers, which increased interest despite lower self-efficacy. In contrast, negative interest in theory often stems from perceiving theoretical work as irrelevant and lacking practical applications [41]. These studies used qualitative inductive approaches to identify categories and subcategories from students' stories about their preferred methods in physics and career interests.

In our prior work on interest formation in specific subfields, we found that students' interest is shaped by exposure, perceptions, and outcome expectations [28,42,45]. Many juniors and seniors are unfamiliar with various physics subfields, revealing a gap between the standard physics curriculum and contemporary areas of physics research. For well-known fields like astronomy and astrophysics, we found that students often had unrealistic expectations about the work involved, leading some to lose interest when they realized it involves desk work and programming rather than on-site telescope observations [42], which is similar to another study involving astronomy graduate students [22]. Negative experiences in high school biology and chemistry also discouraged some students from pursuing subfields that overlap with these sciences, such as biomedical physics [42].

III. METHOD

A. Interview protocol

We conducted 27 semistructured individual interviews with college students from different academic years between 2020 and 2022. The interview protocols were based on the SCCT framework and covered all of the colored SCCT constructs shown in Fig. 1. The detailed interview transcripts are included in the Appendix. All of the interviews asked about students' decision-making processes related to physics subfields, while a subset also asked about students' interests in the methods employed in physics (e.g., experimental, theoretical, and computational) and their intent to pursue graduate school or employment opportunities after graduation. In this paper, we will only focus on findings associated with the subfield of physics that students identified as their interest.

B. Recruitment and participant demographics

We initially interviewed seven physics majors in their third or fourth year of college, who were recruited from summer research programs and an online chat community (Discord) for physics majors at one institution [40]. In the summer and fall of 2020, we expanded our study with ten additional interviews with physics majors doing summer research at six different institutions across the United States [28]. Finally, during the late summer and fall of 2021, we used various recruitment tools such as emails, posters, and Discord messages to recruit ten more participants from a single institution, many of whom were not participating in undergraduate research. Table I summarizes the participants' demographic characteristics, and Table II briefly outlines their subfield of interest. For brevity, we use the label astrophysics to encompass both astronomy and astrophysics and the label biomedical physics to encompass biophysics, medical physics, and nuclear medicine.

We obtained consent from the interviewees and conducted video-recorded interviews using Zoom. The interviews typically lasted between 60 and 90 min. Most participants received a \$10 gift card as a participation incentive. However, interviews that were part of a longitudinal study received a \$20 incentive to recognize the effort of continued involvement in the study [28].

C. Coding and analysis

We aimed to understand the different ways students perceive and understand different subfields of physics. We

TABLE I. Demographic characteristics of participants.

Data collection	Years of study			Gender			Race					
$N = 27$	Soph	Jr	Sr	Man	Woman	Nonbinary	White	Hispanic	African American	Asian	Multiracial	
From 8 different institutions	4	8	15	19	6	2	17	3	1	3	3	

TABLE II. Subfield interests among participants. Biomedical physics includes biophysics, medical physics, and nuclear medicine. Astrophysics includes astronomy and astrophysics.

Subfield of physics	Total
Acoustics	1
Astrophysics	11
Biomedical physics	6
Condensed matter physics	1
High-energy physics	2
Nuclear physics	1
Optics	1
Physics education	3
Quantum information	1
Total	27

analyzed the semistructured interview transcripts using the Dedoose software, which is a tool designed for qualitative data analysis to identify distinct categories [46]. The initial step in the data analysis process was deductive coding, which involved identifying and labeling SCCT-related excerpts within the data. This step involved assigning specific codes representing different SCCT constructs, such as *learning experiences*. Within each SCCT construct, we then used a thematic approach to identify patterns and subcategories. For instance, one emergent subcategory for *learning experiences* focused on the variety of *experimental experiences* students had during their undergraduate studies.

Throughout the coding process, we utilized several methods to provide evidence for the validity and reliability of the coding scheme. Initially, one researcher (P. C.) developed the first-pass coding scheme and generated the codebook to identify SCCT categories and subcategories during the first data collection phase. Subsequently, another researcher (R. B.) refined the codebook and applied the same scheme during the second round of data collection. A third researcher (D. Z.) then used the coding scheme on random sections in our data in order to establish interrater reliability testing. These codes were further discussed, and revised in weekly meetings with (B. Z.). We continued to discuss and refine the codebook until all disagreements were resolved.

D. Organization of the results

The results are divided into two subsections. In the first part, we present the subcategories discussed by students and categorize them according to the relevant categories of SCCT. These results align with the first research question and the first stages of data analysis, which involved a priori coding based on the SCCT categories followed by a thematic grouping within each category. This approach allowed us to gain a comprehensive understanding of the students' experiences within different physics

subfields, as well as how these aligned with the SCCT constructs (Sec. IV). In the second part (Sec. V), we use the results of the SCCT deductive coding and thematic inductive analysis to compare students' perceptions and experiences within two physics subfields, specifically biomedical physics and astrophysics.

IV. RESULTS FOR RQ1: INTEREST FORMATION WITHIN SCCT CONSTRUCTS

This section focuses on research question 1 and presents the themes and findings related to four SCCT constructs: learning experiences, self-efficacy, outcome expectations, and proximal environmental influences. Within each SCCT construct, we organized the findings according to the emergent subcategories that captured the diversity of student responses. It is important to note that not all students mentioned every subcategory. We wanted the subcategories to span the range of ideas expressed in students' decision making regarding physics subfields.

A. Learning experiences and subfield choice

As expected, learning experiences played an important role in fostering students' interest in specific subfields of physics. Figure 2 shows factors that represent the diverse learning opportunities during undergraduate studies. For example, under the SCCT construct of *learning experiences*, we identified subcategories such as academic coursework experiences, experiential learning opportunities, extracurricular clubs, and self-directed learning. In the following sections, we will delve into each subcategory of learning experiences, emphasizing their importance in students' interest in their chosen subfields. We systematically recorded and analyzed the frequency of specific subcategories to understand how commonly they appeared across interviews.

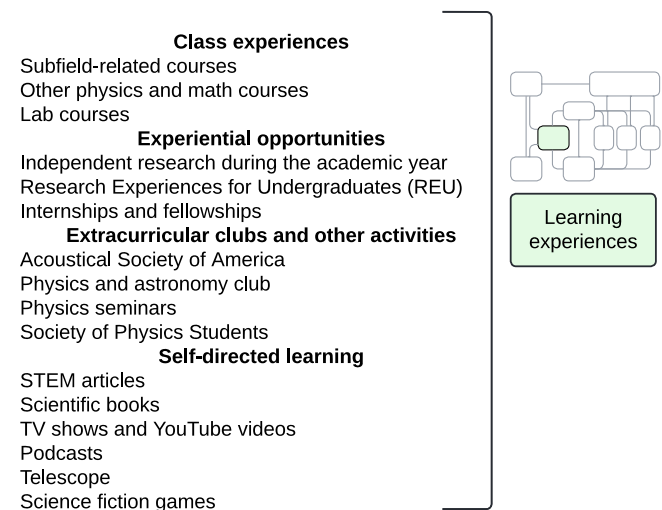


FIG. 2. Learning experiences expressed by undergraduate students related to their desired subfield of physics.

Class experiences refer to academic coursework that played an important role in shaping students' comprehension and perspectives on various physics subfields. These experiences emerged from reflections upon courses that were completed at the university level, which enriched their positive view of a preferred subfield. Academic coursework experiences may include one or a combination of courses focused on specific subfields, along with core courses, including laboratory courses, preparing students for a bachelor's degree in physics. Students most often mentioned subfield-specific classes as influences on their subfield choices. For example, Brett, who was interested in physics education, took many pedagogy classes as part of his bachelor's program, which included a teaching certification. These learning experiences offered by his institution influenced his interest and confidence to become a high school physics teacher after he graduated. He said, "I know a lot about teaching ... I have already had experience. I was scared when I first started that very first education class I took. I didn't know if I [would] be a very good teacher. But the more and more I have [done], the more I have gained confidence in teaching. I do feel really confident about it" (Brett, Physics education).

Physics and math courses not specifically tied to the subfield sometimes served as foundational knowledge and provided relevant skills and concepts necessary for future work. For instance, Mike said he was interested in quantum information, and coursework in related subjects, such as classical mechanics and computational physics, gave him knowledge and confidence. He said, "I have both the [experiences]; computer science background, physics background, and computational physics. I think pretty confident" (Mike, Quantum information). Similarly, Thomas, who described an interest in particle physics and was engaged in research involving extensive coding in granular materials, expressed, "I do a lot of math classes and those help with the coding side and kind of the statistical mechanics ... It's mostly been applied to a deeper understanding of [what] the papers are discussing and [have given me a better grasp of] what I'm being asked to do. I'm in two different stats classes right now and both of them require a ton of Python. In the soft matter research that I do I use Interactive Data Language (IDL), ... A lot of code. But just getting the experience of problem solving using code. I can definitely apply those concepts and I understand better" (Thomas, Particle physics).

Some students also reported that laboratory and experimental physics courses empowered them to pursue their specific areas of interest. For instance, Frieda stated, "The habits that I learned last year in advanced lab, those kinds of skills have been really useful as a foundation for being a good scientist in general, in terms of keeping good records and having reliable results." She also mentioned learning to use "all kinds of different [tools] that were specific to those experiments but also often used in other

places and foundational to our modern technology. So I think it was worth it" (Frieda, Astrophysics).

Experiential opportunities offer hands-on scientific practices and deep engagement in focused areas through faculty-led projects, summer programs, and internships. Bruce emphasized the importance of depth in research projects, highlighting how that allowed him to independently tackle challenges and develop a comprehensive understanding of specific topics "without immediate instructor assistance." Through his research project during the academic year, he noted that he "fully understands something specifically and very well." He stated, "To understand, to the point where I would understand it inside and out, I think that happened with my research project" (Bruce, Condensed matter). His statement about understanding his research project "inside and out" could be interpreted as having high self-efficacy, which then deepened Bruce's interest in his subfield. Moreover, experiential learning opportunities provided many benefits for students, such as fostering personal and professional growth, as Helen experienced during a junior year research opportunity. She said, "Because I had the ability to travel and present my physics research and meet other students doing research and I think that [helped] my confidence grow as a physicist" (Helen, Nuclear medicine). As Helen's quote suggests, research experiences provided some students with a sense of community and belonging. Interacting with peers who shared similar interests was empowering, as demonstrated by Sophia's positive experience in her biophysics research lab. Sophia said she had a positive experience and sense of connection in her research lab, where she had the opportunity to collaborate with other undergraduate and graduate students. She said, "My research mentor had about 50–50 women [in her research lab]. One of the students was partially mobile, he's in a wheelchair. Nobody thought that was weird. I was working with other people who look like me. That was pretty sweet. This is probably why I feel welcome and comfortable. I felt welcome as well as safe. Most of the time, I think I feel really confident in doing the experimental work. I know I don't know everything, but I know how to ask. I know how to find people who does." By interacting with peers who have similar values, interests, and experiences, Sophia found a supportive community that understood and appreciated her work. All of these factors are likely to increase long-term involvement in the subfield. Sophia added, "I hope that getting a bunch of experience and then looking for graduate school. I'm expecting to get a bunch of experience in it and I can go find jobs that are like, you have done all of these things, you will be a good fit" (Sophia, Biomedical physics).

Students also commented on the role of research mentors in their subfield choices. The guidance, shared experiences, passion, and insights into various subfield areas inspired students and fostered a desire to learn more about a

particular subfield. For instance, Thomas said, “I’ve been working in granular materials for a while, but every time I’ve learned about anything in particle physics, or accelerator physics, I just really wanted to learn about it ... The thing that drew me to the granular materials work was my research mentor. He has this incredible energy about him. I vibe with him well. I think our personalities mesh pretty well. We are both very energetic and optimistic, so I just really wanted to work with him. Then from working with him and experiencing the energy he gives to a room for so long. I have been drawn more and more into the work” (Thomas, Particle physics). Similarly, Joshua emphasized his mentor’s qualities of kindness and effective leadership, that may have influenced his decision to pursue high-energy physics research in graduate school.

A majority of students who discussed research experiences were in their final year of their bachelor’s program, with fewer juniors, sophomores, and one freshman also participating. One reason that subfield interest may not form until later in college is that students do not get access to the research and elective course experiences until later in their studies. However, early exposure to undergraduate research and elective coursework has great potential to stimulate curiosity and shape interests in specific physics subfields.

Internships also had a positive impact on students’ subfield interests. For instance, Sean stated that his internship not only provided practical skills, but also helped him gain a foothold in the field, boosting his confidence and skills considerably. He said, “When I came into college, not as confident nowhere near as confident as I am now. I’m still definitely building confidence with it. My coding experience before college was very low [but] not nonexistent. I did have an internship working as a data analyst. So that kind of got my foot in the door.” He continued, saying “after working on computational physics he really got a taste for using code consistently across different classes” (Sean, Astrophysics).

Extracurricular clubs and other activities refer to non-traditional learning. Extracurricular outreach activities fostered a strong peer community, which increased students’ interest in specific physics subfields. Kirk, who was interested in biophysics, shared how he found inspiration and ideas by interacting with different students through his participation in the Society of Physics Students chapter at his home institution. Caleb, interested in biophysics, joined the physics and chemistry club and engaged in fun experimental projects during club meetings, such as making a ping pong cannon that shot the ping pong ball and synthesizing ibuprofen just starting from a benzene ring. He described how these hands-on experiences not only linked his interest in chemistry but also connected him to the subfield of biomedical physics.

Similarly, Grace, interested in astrophysics, shared her involvement in the physics club at her institution, where

they organized various events to build a sense of community. These events include watching physics videos together, participating in physics trivia, and engaging in other fun activities to build community among members. In addition, the club hosted open houses and astronomy nights, providing Grace with the opportunity to work on the rooftop and set up the telescope for the public to look at the sky and engage in scientific discussions. Generally, physics-related extracurricular clubs and activities were less commonly discussed compared to research experiences and coursework among the students interviewed. This could indicate a tendency for students to prioritize academic experiences over extracurricular involvement or a lack of opportunities. However, for those students who did participate in physics-related extracurriculars, there were positive impacts on interests within the subfield, fostering community, and furthering practical applications of physics concepts. Those who engaged in informal science education as part of their extracurricular activities saw gains in knowledge and recognition, which can boost physics identity [14].

Self-directed learning refers to instances where students proactively engage in independent exploration. They often seek diverse resources, including books, online materials, academic journals, YouTube videos, and social media science communicators, to delve into specific subfields that align with their interests. Self-directed learning allows students to delve deeper into a subfield beyond formal academic structures, such as courses, and leads to an improved understanding and greater awareness of the latest news and developments. Sean, for example, expressed his fascination with astrophysics and his proactive approach to learning. To deepen his understanding of astrophysics, he regularly searched for supplementary material, such as instructional guides, books, or other reference materials that were designed to provide detailed explanations. Self-directed learning often begins before college, unlike other learning experiences that are typically inaccessible before higher education. For instance, Beth discussed her interest in astrophysics and her reading habits. She said when she was a child, “We had books from black holes and stuff that I would read, and then my mom would yell at me to go to bed. It is two in the morning!” (Beth, Astrophysics).

B. Self-efficacy and subfield choice

Self-efficacy refers to an individual’s perception of their ability to perform and accomplish a task. To gain a deeper insight into students’ self-efficacy, we looked at it through two perspectives: First, we explored the various sources for *developing self-efficacy* among students. Second, we investigated the *benefits of having higher self-efficacy* in relation to making choices within a specific subfield. Figure 3 summarizes the self-efficacy subthemes.

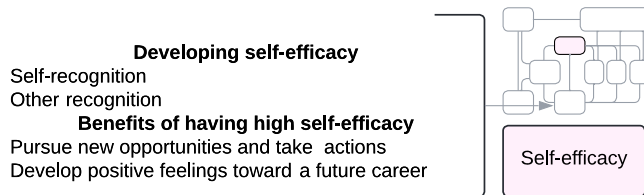


FIG. 3. Self-efficacy expressed by physics majors.

1. Developing self-efficacy

Students with limited learning experiences often felt less confident in their abilities to pursue their desired subfield. However, as they learned more about their chosen area, their self-efficacy, or belief in their ability to succeed, changed. This transformation was influenced by both self-recognition, where students saw their own growth and potential, and other recognition, where they were recognized and praised by peers or mentors. This cycle of recognition boosted their motivation to learn, engage in research, and pursue their desired subfield in physics.

Self-recognition, the understanding of one's own capabilities and potential, was developed through various learning experiences and directly impacted students' self-efficacy. Our data showed a clear link between students' self-efficacy and their past achievements and learning experiences. According to SCCT, self-efficacy should also influence interests in specific physics subfields. A student's successful academic performances, such as achieving high grades, could lead to a heightened self-recognition and investment in their learning, motivating them to pursue related opportunities and specific physics subfields. One student, Emma, exemplified this relationship between past successful performance and self-efficacy. She said, "I am pretty sure I will get accepted [in grad school in physics education], I have good grades and a good GPA, and I am very clear about what I want ... I feel confident about it. I am nervous, but I have worked really hard to prepare [for the] licensing program." She added that she might not be fully ready to start teaching and may encounter some challenges, but she feels "prepared enough to work through those issues" (Emma, Physics education).

Students who received positive feedback and *other recognition* from various sources, such as scientists, peers, family, and the public, appeared to demonstrate increased confidence in their ability to achieve academic and career goals. This other recognition can include supportive verbal encouragement (e.g., telling the student that "you can do it," "you did a good job," or "you are a problem solver") and opportunities for students to present their work within the scientific community (e.g., sending the student to the conference). As mentioned in Sec. IV A, the astronomy club open houses and astronomy nights allowed Grace to set up the telescope on the rooftop, gaining public recognition while facilitating outreach events. Similarly, Joshua shared, "My mentor says, 'You can do it just like before.'

So, my mentor gave me much confidence and erased my worries" (Joshua, High-energy physics).

Emma, who was interested in teaching, said she received additional recognition from her academic advisor, who also leads many of the math education preparation program courses. Emma said that another mentor, who is also her instructor and supervises her as a learning assistant, is "constantly pushing [her] to go to graduate school." Emma expressed gratitude, stating, "When I first started at my institution, she was the chair of the physics department and helped me determine which classes I needed to take. She's been a big like support for me, continuing and finishing the [program]. She's like, 'you could just get a masters and then teach' so she really wants me to keep doing my own education. She has definitely been huge encouragement" (Emma, Physics education). For Beth, the other recognition stemmed from recognition by her research mentor. She said, "Most of my confidence comes from my mentors and any research experience I have done ... Because I do research, and then the mentors come up with a lot of good things to say about me and invite me to conferences" (Beth, Astrophysics). Beth has been invited to present her research findings at conferences, which has given her opportunities to share her work and receive recognition from the scientific community for her research efforts.

The overall culture within a field, particularly its perceived work-life balance, emerged as another influence on students' self-efficacy, as illustrated by Beth's experience with astrophysics. She stated, "I'm talking to people and just observing it myself, it looks like they're making great strides in [the community] in the past couple of years alone, so that makes me feel more confident and being able to enjoy that life" (Beth, Astrophysics).

2. Benefits of having high self-efficacy

Thus far, we explored various factors contributing to developing students' self-efficacy. In the subsequent section, we identify themes related to students' high levels of self-efficacy, which significantly impacted their decision-making process regarding subfield choices and future career paths. This finding aligns with the SCCT diagram, where self-efficacy mediates between learning experiences and developing interest and subsequent choice actions in the chosen subfield.

Consistent with research findings, a higher level of self-efficacy encourages students to *pursue new opportunities and take action* [47]. Models of self-efficacy predict that students who strongly believe in their capabilities are more motivated to actively seek new learning opportunities. In our data, many students expressed their willingness to explore more research positions and engage in new learning experiences. For example, Mike said, "I feel I always have stuff to learn ... and whatever need rises, I could learn." He "is researching with a professor to kind of dip my toes into the field of quantum information" (Mike, Quantum

information). Bruce said he is confident in his ability to conduct experimental research in condensed matter physics in the future because he possesses the fundamental skills required; “I have the basic tools to be able to understand how do something. I know how to look up new tools. I know how to figure out how the tool works. I know how to try to set it up and try to troubleshooting, I think that’s kind of the foundation for experimental work and I have kind of a precursor idea of how to have enough of a physics background to be able to understand what goal [I] actually want out of the experiment. So, I do feel confident.” Bruce emphasized how his high self-efficacy in his current research contributed to his plan to continue research in a similar area.

Students with higher self-efficacy were more likely to *develop positive feelings toward a future career* in a specific subfield. Emotional factors, physics identity, and a sense of belonging are not explicitly captured in the SCCT map. However, the relationship between self-efficacy and a sense of belonging is mutually influential [28]. Pursuing an area of interest brings satisfaction, happiness, and a sense of fulfillment. For example, Thomas expressed his confidence and positive feelings about the community in his chosen subfield of high-energy physics. He said, “I feel I am confident. I like the community. I have worked with a few different professors, and we have a research group. I have talked to a bunch of people from different places and have really liked it so far. The work is fun” (Thomas, Particle physics).

Some students had high confidence and positive emotions, which enhanced their interest in their chosen subfield of physics. For instance, Max said he felt that “I probably could do well in it. I think I have the skills necessary to go into the subfield. I feel physics education is what suits me really well” (Max, Physics education). Max is confident that he has the skills to excel in physics education, which strengthens his interest in the field.

C. Outcome expectations and subfield choice

When students contemplate their future careers within their chosen subfield, considering their outcome expectations becomes very important. Outcome expectations are beliefs about what a job or future career may be like if they were to pursue a particular subfield. These expectations varied widely among students, including factors such as job security, commonly used skills, maintaining a healthy work-life balance, and achieving personal fulfillment. Figure 4 provides a summary of the common outcome expectations expressed by students about different subfields of physics. In the following sections, we categorize these outcome expectations into three main groups: exploring career paths, skill development and acquisition of expertise, and integrating work and personal life.

Career paths refers to the process of investigating and considering various options for students’ future

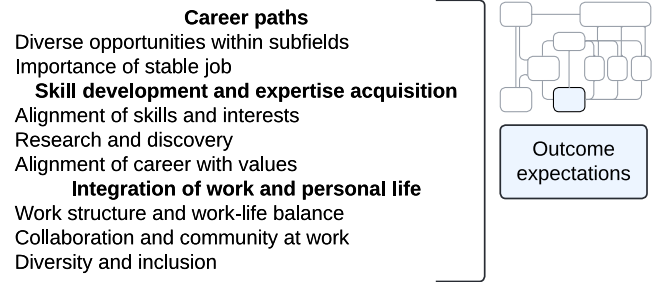


FIG. 4. Outcome expectations expressed by undergraduate students.

professional paths. Across different subfields, students noted the *diverse opportunities within subfields* due to the nature of the subfield. For example, Sophia discussed her ideas of pursuing a career in the field of biophysics. She said, “I could be working in a variety of things. I could see being doing medical testing. I could [be] in a pharmacy. I could see doing biotech. [It] is really big ... I can do data processing stuff. So, ideally, I would be working in a lab, trying to do medical research and poking at stuff, but also I think there are a lot of good physics options for these based on the interest in biophysics that I have and that I have worked in” (Sophia, Biomedical physics). We also noted that students with high self-efficacy were more open to exploring different career opportunities within their chosen subfield of physics. For example, David said he has explored “companies that are doing sonar research as well as different national labs that are doing research in acoustics and universities where I could potentially [pursue] a faculty position. I do not know where I would end up going, but I could see myself going any of those three routes” (David, Acoustics).

One outcome expectation expressed by several students regarding their preferred subfields was the *importance of a stable job*. For example, Helen acknowledged that while money is not the primary motivator in pursuing nuclear medicine, money can enable her to contribute to society in other ways. On the other hand, David expressed satisfaction in finding a field he enjoys (acoustics) and recognized its favorable salaries based on published statistics. The expectation of good financial and job security was not restricted to applied subfields. Being a self-described “practical person,” Frieda emphasized positive beliefs about financial and job security in her pursuit of astrophysics. These students viewed income and jobs as a motivating factor in their subfield choices, giving them a sense of security and stability.

Skill development and expertise acquisition refers to the expectations of using specific skills as part of routine work within a chosen subfield. Immersing oneself in learning experiences within the subfield offers valuable expertise and specialized skills. The students anticipated gaining a deep understanding of the topic, conducting thorough research, and ultimately becoming experts in their chosen

field. The *alignment of skills and interests* with the specific characteristics of a subfield effectively allowed students to identify fulfilling career paths. By understanding the unique nature and requirements of different subfields, students made better informed decisions about their career paths. For instance, Dalton said that the best part of astrophysics involved employing “beefy mathematics to derive equations and analyzing observational evidence” (Dalton, Astrophysics).

Kirk’s explanation of why he enjoys biomedical physics reflected his enthusiasm for the nature and scale of the subfield. He expressed, “The reason I like biophysics is because ... I love the environment.” He said, in his mind, biophysics involves more than just “observing through a microscope and taking measurements.” He said, “In reality, I think it is like taking videos of things moving at cell scale, and I know some people measure that kind of motion. So, taking the videos and analyzing it seems really cool to me” (Kirk, Biomedical physics). He said he finds the idea of visualizing these motions fascinating, even though they may not be visible to the naked eye, “Because you’re actually seeing something move. Like obviously, I’m not seeing it with my eyes, but you’re still seeing it.” This ability to visualize and analyze dynamic processes at a microscopic level clearly captivated Kirk’s curiosity and imagination. Kirk also shared his dislike for chemistry, citing a heavy burden of memorization as a drawback. He contrasted this with physics, where he found joy in the problem-solving aspect. For Kirk, physics offered understanding through problem solving rather than rote memorization, making it a more engaging and enjoyable subject for him.

When exploring *research and discovery* careers, students anticipated getting deep into research because they wanted to make discoveries and to contribute meaningfully to their subfield. For instance, Adam provided examples of research-oriented career paths within nuclear physics. He mentioned possibly being a “university researcher who is just doing research” (Adam, Nuclear physics). In addition, Adam said that the outcome expectation extended beyond exploring new knowledge, as it also included sharing findings through publications.

Prioritizing an *alignment of career with values* was evident for students who chose physics subfields that more directly helped people and society, such as medical physics and biophysics. For instance, Cale expressed his perspective on astrophysics, acknowledging, “In our lifetime, I don’t think we’re gonna get a human out of a light-year distance from Earth. So that exploration of space to me, it’s interesting, but at the same time, is it realistic?” Cale questioned practicality and tangible impact of astrophysics. Conversely, he highlighted the benefits of medical physics, emphasizing the potential to “help people” in need. Nuclear physics also held promise for advancements in medical scanning technologies, although he was “not too much a fan of the weaponization part of it, but it is a double-edge

sword” (Cale, Medical physics). This highlights how students balanced their curiosity with values that pushed them to make a difference.

Integration of work and personal life refers to outcome expectations that focused on the overall lifestyle connected with a subfield, rather than considerations of the day-to-day work routine. Some students wanted careers in subfields that offered good *work structure and work-life balance*. For instance, some students recognized that particular careers within physics might offer opportunities to travel to conferences and present their work. For example, Beth mentioned that she “could hopefully be able to have some kind of work-life balance ... If I can travel to conferences to do work, I would love that” (Beth, Astrophysics). We also found that some students were influenced by their mentors and the way they approach their work. For example, Bruce mentioned that his mentor demonstrated a balanced way of doing research, which had a significant impact on him. He said, “a sense of how he does research ... He’s not always super stressed about everything. He is not overworking himself. This idea that you can be a researcher and not overwork yourself all the time is also quite enticing” (Bruce, Condensed matter physics). It led him to realize that being a researcher does not necessarily mean constantly overworking oneself, but that there is a way to maintain a balance between work and personal life. This realization gave Bruce a new perspective on pursuing a career in condensed matter physics. Another aspect of worklife mentioned by some students was a desire for *collaboration and community at work*. These students wanted to work in a subfield that involved meaningful social interactions, enabling them to directly address societal challenges and contribute to a more equitable and sustainable future. A desire for collaboration and community also meant seeking careers that avoided isolation and fostered social interaction. Max, for instance, expressed his preference for being in a subfield that offers social connection and engagement with people. He said he is not looking at careers where he is “just sitting in a lab by myself, social is important to me.” He was a part of social groups at his institution and said, “I’ve always had a lot of very close [friends], which makes me want to do like something more social and more extroverted” (Max, Physics education). Additionally, students emphasized the value of scientific teamwork in their future careers. Sean expressed the importance of “spending time with people who are [highly] focused on astrophysics,” allowing for deeper engagement and learning (Sean, Astrophysics). Similarly, Helen said she found the idea of medical physics intriguing because of the physics aspect and because it provides opportunities to interact with professionals from “different fields such as physicians, patients, biologists, computer scientists, and engineers.” She stated that this collaboration aspect allows for a broader perspective and the exchange of knowledge and ideas within the STEM-

related fields, “You are working with not just other physicists, you are working with a bunch of other people in STEM-related fields” (Helen, Nuclear medicine).

Some students considered the importance of *diversity and inclusion* for their future careers, and this influenced the subfield in which they had the most interest. For instance, Grace said, “I’ve been thinking a lot more on working as like faculty. I’m not sure about [working in] a company. I’d have to do a little more research into that and what the atmosphere there is like. I feel pretty strong [about pursuing astrophysics]. I think I feel physics and astronomy, particularly, have been very male-dominated fields. In many astronomy classes, there is a notable focus on the historical context, which often highlights the contributions of male figures who have received Nobel Prizes ... But this is the woman that did all the work. So, I feel pursuing that specifically, at a historically women’s college is pretty strengthening. I like it. I see myself as a physicist” (Grace, Astrophysics). Although Grace said she noticed these negative elements in the male-dominated culture and historical focus on male achievements in physics and astronomy, she still wanted to pursue astrophysics. She saw herself as a physicist and felt that pursuing this field at a historically women’s college was empowering and aligns with her passion. She also appreciated the supportive environment where her contributions were valued and was inspired to advocate for gender diversity in the field.

D. Proximal environmental influences and subfield interest

During interviews, students discussed how environmental factors in their institution and personal lives could impact their subfield choices. The analysis of these factors revealed a range of influences and barriers that the students considered when making decisions about their subfield of interest. The environmental influences discussed by the students are summarized in Fig. 5.

COVID-19 pandemic influences are an external factors that influenced some students’ choices regarding their desired subfields and future career paths. Seven students who were interested in various subfields mentioned the COVID-19 pandemic’s impact on their interests. Cale, for instance, said, “The COVID-19 pandemic [is] pushing me towards [medical physics] a bit. The medical field in general is suffering pretty hard from a few various broken points ...” He emphasized the challenges facing the

medical field, especially in the United States, “Given the current state of humanity, I feel that contributing to this area can only help. The pandemic has added immense stress to the system, and even with the additional effort, it still does not seem to be enough. This kind of strain is incredibly detrimental, and more manpower is needed. I know I am just one person, [but every contribution counts]” (Cale, Medical physics). Thomas’s statements highlight the nuanced impact of the COVID-19 pandemic on students’ career decisions, particularly in the context of graduate school aspirations. Initially, Thomas’ concerns centered on financial barriers, a common apprehension for prospective graduate students. However, upon learning that most physics graduate programs offer financial support, his focus shifted toward meeting admission requirements in the face of academic challenge created by the pandemic. He said, “What [used to] scare me was money, I was afraid of how much it would cost, and then realized that most physics programs are paid for. So, the thing that scares me the most is just getting in at this point. I’m constantly worried that I don’t have the right references or not good enough grades and things like that. I found an article in the Physics Today magazine about applying for grad schools with a COVID-19 resume. I’m definitely worried about getting in” (Thomas, Particle physics).

Institutional influences refer to how the specific university, college, or educational setting affects a student’s academic and career choices. Barriers, such as a lack of support from the institution, limited availability of coursework, or limited availability of research opportunities in particular subfields were identified as potential challenges that could affect subfield choices. For example, Frieda said, “We do not have opportunities for astrophysics research at my school, and so I have not had the opportunity to get involved yet, and if we had classes in astrophysics at [my school], I would 100% take them, but we do not” (Frieda, Astrophysics). Leo is concerned about the “shortage of medical physicists” at his institution. He said, “Nobody knows about the field because there is no outreach. It is not like astrophysics or condensed matter physics that most people learn about it during the last couple of years of undergrad” (Leo, Medical physics). The academic culture and available institutional resources can influence students’ interest in chosen subfield and their career paths.

Disciplinary culture influences refers to how the inherent values and perceptions within the physics community can elevate certain subfields, making them seem more important or respected, which then guides students’ decisions about what to study and how much they feel they fit in. For instance, Brett thought about getting a master’s in education, perhaps while teaching high school. However, he said, “I’ve always wanted a Ph.D., just to have the [title of] doctor... In physics, it’s very much [everyone] being pushed into a Ph.D. track” (Brett, Physics Education).



FIG. 5. Proximal environmental factors expressed by undergraduate students.

TABLE III. Comparing SCCT constructs: astrophysics and biophysics subfields.

Subfield of physics/SCCT constructs	Astrophysics	Biomedical physics
<i>When interest forms</i>	Prior to college	During college
<i>Learning experiences</i>	Accessible through popular science media High school and college classes Strong precollege interest	Undergraduate research experiences
<i>Outcome expectations</i>	Secure fulfilling careers Contribute to discoveries	Help others and make a positive impact Enhance the overall quality of life for society

V. RESULTS FOR RQ2: COMPARISON OF TWO SUBFIELDS

The analysis of research question 2 focused on exploring the differences in how interest is formed between two specific subfields: biomedical physics (including biophysics, medical physics, and nuclear medicine) and astronomy and astrophysics. Studying these differences provided valuable insights into the factors that shaped interest in various subfields. We observed many similarities in self-efficacy and proximal environmental influences between those students interested in biomedical physics and in astrophysics.

There were significant differences between how often students mentioned particular learning experiences or outcome expectations. Table III illustrates the main differences in learning experiences and outcome expectations between astrophysics and biomedical physics subfields, which we review in the following subsections.

A. Exploring learning experiences: Biomedical physics versus astrophysics

When comparing the learning experiences in astrophysics and biomedical physics, distinct patterns can be observed. The popularity of astrophysics can be attributed to four main factors: its portrayal in popular culture and popular science media, exposure in high school and college courses, strong intrinsic curiosity, and personal experiences looking up at the moon, stars, planets, and sun, and using telescopes. Popular science inspired students' interest in astrophysics. Beth pointed out, "Because astronomy is really big in our culture, I think everyone has heard of astronomy at one point" (Beth, Astrophysics). Some students mentioned that their exposure to astrophysics began in high school, with supportive high school teachers fostering their interest in astronomy. Finally, many universities offered college classes in astronomy and astrophysics, which allowed students to gain a deeper understanding of the field, solidifying their interest and expanding their knowledge. Dalton said, "I absolutely adore [astronomy]. It is loads of fun." For him, the experience is enjoyable and less focused on equations, allowing him to "just get to enjoy learning about how things roughly happen" (Dalton, Astrophysics).

In contrast to astrophysics, biomedical physics was not commonly encountered through popular science media or high school or college coursework. Instead, interest in biomedical physics was primarily influenced by engaging in research and practical experiences within the medical field. All six students mentioned research as a key factor in developing their interest in the biomedical subfield. So, while astrophysics often captured students' attention before college through its presence in popular culture and in college through coursework, the formation of interest in biomedical physics relied more heavily on research opportunities and other observational and participatory activities, which typically did not happen until the later stages of an undergraduate degree. For example, Caleb said that he found great value in job shadowing doctors, which provided him with firsthand insights into the hospital environment and further fueled his interest in biomedical physics.

B. Exploring outcome expectations: Biomedical physics versus astrophysics

When comparing outcome expectations between students with high interest in astrophysics and biomedical physics, we saw differences in the values they expressed regarding their future careers. These value-based outcome expectations overlap with value categories in the motivation theory of Eccles (e.g., particular attainment values or utility values) [48]. In both SCCT and the expectancy-value theory of motivation, these beliefs (i.e., values) affect one's motivation to pursue goals and actions in a particular direction.

Ten students interested in astrophysics believed this path would give them the opportunity to engage in research, gain new knowledge, and contribute to discoveries within the field. Sean expressed a desire to experience discovery and make an impact (Sean, Astrophysics). Similarly, Grace said, "I would love to discover something or make some sort of contribution to a discovery and to just explore uncharted territories" (Grace, Astrophysics). Moreover, multiple students were confident they could find a good job in an astrophysics-related career.

In contrast, five students pursuing careers in biomedical physics expressed that this career path would let them make a positive impact on others and society. This value-based

outcome expectation motivated these students to apply their scientific knowledge and skills to improve the quality of life for others. Helen emphasized the significance of “having short-term effects on whom you impact. [Look] back on a list of patients and think about all the people you have impacted and helped their families and like save their lives” (Helen, Nuclear medicine).

VI. DISCUSSION AND CONCLUSIONS

Our research question 1 (RQ1) aimed to understand how, through the lens of social cognitive career theory, factors such as students’ learning experiences, self-efficacy, outcome expectations, and proximal environmental influences were associated with their interests in different subfields of physics. Our findings revealed that the students gained knowledge in a variety of ways, drawing on class experiences, research opportunities, extracurricular activities, and self-directed learning.

Moreover, our exploration of self-efficacy and its role in subfield choice revealed that students’ beliefs in their abilities were influenced by both self-recognition and other recognition, which aligns with other physics education research on self-efficacy and physics identity [14,49,50]. For instance, facilitating extracurricular informal science education activities led to recognition that boosted self-efficacy and identity formation as participants treated the facilitators as experts, even though they had not completed their undergraduate degree. Students, such as Grace, who engaged in informal science education highlighted the link between self-efficacy and recognition by self and others. Our findings align with those of the study by Prefontaine *et al.* [51], which highlighted the unique role of informal teaching and learning programs in shaping students’ interests in physics. Such programs offer opportunities for both participants and facilitators to interact in a way that fosters the development of a strong physics identity. Furthermore, courses often provide structured opportunities to master core physics concepts and skills, while research experiences enable students to engage in authentic problem solving and receive validation from mentors and peers.

Our study highlighted the importance of outcome expectations, which refer to students’ perceptions about the potential outcomes of their career decisions, whether those are realistic or not. For example, popular science can provide exposure to specific subfields, such as astronomy. However, it often creates unrealistic outcome expectations for students, such as spending lots of time at telescopes rather than doing mostly data analysis and modeling at a computer. Moreover, proximal environmental factors within their institutions and personal lives, such as the availability of courses, may limit or positively influence students’ decisions to pursue specific subfields in physics. While SCCT provided a comprehensive framework for understanding interest formation, our second research

question (RQ2) delved into a comparative analysis of interest formation across two specific subfields: astrophysics and biomedical physics. These subfields were the two most prominently represented across our data, with 11 participants interested in astrophysics and 6 in biomedical physics. If we had more participants from other subfields, it is possible that additional comparative insights would emerge. Our exploration showed significant differences in how and when students encountered learning experiences relevant to the subfield. Substantial interest in astrophysics formed prior to college, while biomedical physics was largely invisible until students encountered it through research or clinical training opportunities. Regarding outcome expectations, we found that students who were interested in astrophysics focused on research, discovery, and securing fulfilling jobs, while those in biomedical physics prioritized impacting society and improving quality of life. Physics departments should facilitate opportunities for students to participate in discussions, collaborations, and shared experiences with peers who have similar interests in specific subfields. Given recent decreases in the number of physics bachelor’s degrees in the United States [1], it is critical to increase awareness and connect students to professional opportunities within physics. One way to do this is to forefront the contemporary subfields of physics and their unique career opportunities. If possible, building subfield communities through clubs and collaborations could boost student engagement and retention. Clubs also provide support and share experiences that can mitigate the impact of fluctuating enrollment by fostering a more supportive and engaging environment [6,52,53]. The physics community could also consider larger curricular revisions that are organized around modern subfields of physics. Currently, most subfields are only included in elective courses during the later stages of a bachelor’s degree. However, successful physics teacher preparation programs show that early opportunities for teaching and pedagogical coursework can support recruitment and retention. Similarly, physics majors could be given early opportunities for experiential learning and coursework linked to modern subfields of physics.

VII. IMPLICATIONS, LIMITATIONS, AND FUTURE RESEARCH

As outlined in our introduction, physics graduates pursue diverse career paths, with significant portions entering employment, graduate studies in physics, and other fields. Furthermore, while certain subfields are popular among Ph.D. candidates, the factors influencing these subfield choices and their impact on long-term employment outcomes remain unclear. Recent reports on physics education, such as the Effective Practices for Physics Programs (EP3) [3] and the TEAM-UP report [4], highlight the importance of fostering career awareness and preparation within

physics education. Our study aims to provide insights into the factors influencing subfield decisions, offering valuable information for departments seeking to enhance career preparation within their physics programs.

Nevertheless, it is important to note the limitations of our research, such as the relatively small sample size. In some cases, we only had one or two students representing certain subfields, which limited any ability to speak about trends beyond biomedical physics and astronomy and astrophysics. Future studies could address this limitation by expanding on our work to explore a broader range of subfields and by including a larger and more diverse participant pool, particularly including greater institutional diversity. Additionally, longitudinal studies would provide valuable insights into how students' interests in subfields evolve over the course of their undergraduate program, helping departments to better support the career decisions of their students.

Another potential limitation of our study is that it was conducted between 2020 and 2022, during the height of the COVID-19 pandemic. The pandemic brought about significant changes to the educational landscape, including quarantine measures, online learning, and social distancing, all of which altered students' learning experiences and proximal learning environments. While some students explicitly mentioned how the pandemic influenced their interest in the biomedical physics subfield, it is likely that the pandemic impacted all students in various ways. Hence, the findings of this study may not fully capture the dynamics of student decision making in a postpandemic context, where students are learning in a more traditional, in-person environment. However, based on previous literature, certain factors, such as research experiences are known to have a significant impact on students' decision making, which we also saw in our data. While the pandemic affected the educational environment, we suspect that many key influences remain pivotal in shaping career paths in both pandemic and postpandemic contexts.

In the SCCT framework, two critical factors are not included: sense of belonging and physics identity. Previous studies have highlighted the significance of these elements in shaping students' interest, retention, and career decisions within the field of physics [14,54,55]. Our future work aims to integrate these factors alongside the SCCT framework, culminating in the design of an assessment for career decision making in physics. We want to do additional research on other facets of interest formation, such as the methods that students want to pursue (e.g., experimental, computational, and theoretical) and how they decide between graduate school or employment after graduating. By examining the details of students' decision-making processes, we can also enhance our understanding of how to recruit, retain, and provide career support for physics majors while also forming their physics identity and welcoming them in to the physics community.

ACKNOWLEDGMENTS

This work was funded through NSF Award No. 1846321.

APPENDIX: SAMPLE OF INTERVIEW PROTOCOL

Intro questions:

- (1) What first caused you to want to study physics?
- (2) Is there some aspect of your college experience that you most want to emphasize? Did you take any gap years? Have you transferred from another institution? How did you end up at [Your current institution]?
- (3) What are your current plans for after graduation? Why did you make that decision? What are you most excited about? What are you most afraid of? What paths do you want to avoid in particular? Why?
- (4) What do you feel you want to get out of college?

Positive subfield questions:

- (1) What subfield of physics are you most interested in doing as a career? For example, astrophysics, optics, nuclear physics, education physics, etc. How would you rank your interest in those subfields of physics?
- (2) What kinds of things do you enjoy doing outside of physics that may relate to physics? Is there anyone who has influenced you towards doing this kind of physics? Do you look up to someone who does this kind of physics?
- (3) What experiences do you have doing work with this kind of physics? What aspects of this type of physics do you enjoy? Have you taken any classes related to this type of physics? Have you done any extracurricular activities related to this type of physics? For example, clubs, research experiences, camps, attending talks, etc.
- (4) Do you feel confident in your ability to do work related to this type of physics? How confident are you in finding a career in this type of physics? Do you see yourself being successful? Why do you feel confident in this type of physics?
- (5) What do you believe are the potential outcomes of pursuing this type of physics? (or) What do you think a career in this type of physics would be like? (or) What outcomes do you hope for from pursuing this type of physics?
- (6) What steps have you taken to pursue your interest in this type of physics? How do you plan to pursue this career? Do you see any major roadblocks or challenges along the way? Have you looked into the types of jobs available to people in this field of physics?
- (7) What are the factors that had the most influence on your decision to pursue this type of physics?

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