Exploring High Interest in Theoretical and Computational Physics Among Undergraduates Through Social Cognitive Career Theory

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This study investigates how strong interest in theoretical and computational physics develops among undergraduate physics majors. While broad exposure to theoretical, computational, and experimental methods is essential for supporting students' career decision-making in physics, curricular and institutional barriers often limit these opportunities. Building on prior work that examined factors for low interest in theoretical and computational physics , we use Social Cognitive Career Theory to understand how high levels of interest are also formed. We conducted in-depth interviews with eighteen physics majors at various stages of their degrees, focusing our analysis on ten students who expressed the strongest interest in theoretical or computational approaches. Using causal mapping, we identified key factors influencing interest development, including self-directed learning, foundational coursework in college and high school, the impact of inspiring instructors and mentors, and early exposure to research. Outcome expectations, such as enjoying mathematical work for theory or wanting practical skills for computation, also played a role in fostering interest in these methods. We hope departments can use these insights to redesign curricula and advising practices to better support student exploration and interest formation across theoretical and computational physics.

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I. INTRODUCTION

To effectively prepare students for careers in physics, departments should provide learning environments that integrate foundational concepts with diverse methods of physics, particularly theory, computation, and experiment. Offering students varied experiences in these methods can spark interest and illuminate potential career paths. However, students' experiences often fall short of this ideal. For example, access to computational coursework may be less common earlier in the curriculum, and curricula frequently emphasize theoretical problem-solving over experimental practice. According to the American Institute of Physics [1], about 50% of physics bachelor's graduates entering the private sector work in computing or engineering, while about half of those in graduate school engage in experimental research, 37% in theory, and 10% in observational methods [2]. Despite these trends, little is known about the factors that might cause these decisions and why some students prefer computational work over theoretical work or theoretical over experimental work. Previous studies have identified factors that affect students' general interest in physics, such as physics identity and recognition [3] and a desire to do research [4]. Our work seeks to provide a more detailed exploration of these factors within specific subfields and methods of physics. This study builds on prior work that examined why some students have low interest in theory or computation [5]. We provide new insights by exploring how other students form strong interests in those same areas. Experimental methods were not the focus of this work due to limited variation in interest levels among the study participants. Future work will focus on experimental interest. We used Social Cognitive Career Theory framework [6, 7] to address one central research question: What factors and experiences contributed to high interest in theoretical or computational physics? By answering this, we aim to uncover strategies that support student decision-making and expand access to a range of physics career paths. In the discussion section, we compare our findings to prior work on low-interest students to highlight differences between high and low interest development.

II. BACKGROUND

Social Cognitive Career Theory (SCCT) [6, 7] (shown in Figure 1) describes how learning experiences shape self-efficacy in one's abilities and outcome expectations, which are beliefs about the consequences of career choices. For example, instructional clarity and a positive classroom environment can enhance students' motivation and self-confidence [8]. Based on our previous work, positive experiences can build self-efficacy and lead to more optimistic outcome expectations, increasing the likelihood of future engagement in a given area [9, 10]. This also supports broader findings that self-efficacy is a strong predictor of academic success and persistence in physics [11]. Similar research in computer science (CS) has found that outcome expectations can also influence why students choose a field [12].

Our study explores the development of undergraduate physics students' interest in theoretical and computational physics, focusing on how learning experiences, outcome expectations, and self-efficacy influence this process within the SCCT framework.

III. METHODS

We conducted semi-structured interviews with 18 undergraduate physics students at a large private U.S. university in Summer and Fall of 2022. We used a convenience sample, recruiting participants through a student Discord group, departmental emails, and classroom visits. For this study, we analyzed data from 10 students (6 with the highest interest in theory and 4 with the highest interest in computation), excluding experimental physics due to generally high interest ratings. The analyzed subset included 4 men, 4 women, and 2 non-binary individuals, 7 identified as White, 2 as Asian, and 2 declined to disclose, and spanned all academic levels, with a majority in their first year(first year: 5, second year: 1, third year: 1, fourth year: 3). Interviews began with participants explaining each method to confirm their understanding, followed by rating their interest from 0 (no interest) to 10 (high interest) a rating of 8 or higher was required to be included as high interest. Throughout this paper, we use shorthand such as (Y1, T-9) for year 1, theoretical interest was 9 or (Y2, C-8) for year 2, computation interest score of 8. Follow-up questions, guided by SCCT, explored influences like confidence in a method (self-efficacy) and expected benefits from pursuing it (outcome expectations). Interviews were recorded, transcribed via Otter.ai, and corrected for accuracy. Participants received a $15 gift card.

Our analysis involved a process of mapping, coding, and synthesizing interview data. For each of the ten high-interest students, we constructed a diagram, which we call an influence map, where each node represented a concise quotation or a brief summary extracted directly from the interview transcript, capturing a specific factor identified by the student as influencing their interest in computational and theoretical methods. The influence map method is a simpler, qualitative version of network analysis, most similar to a concept map. The connections or links between these nodes were drawn to reflect the causal relationships articulated by the students dur-

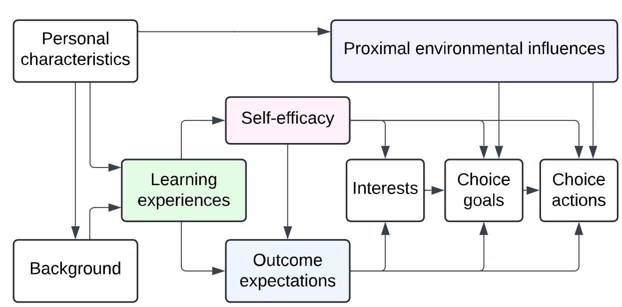

FIG. 1. Map of interrelated constructs within Social Cognitive Career Theory.

ing the interviews. The factors converge on one node indicating the student's interest level. Each statement within a node was categorized into the relevant SCCT construct (a priori coding), such as learning experiences, self-efficacy, and outcome expectations. This stage allowed us to align students' experiences to a well-established theoretical framework.

To gain a broader understanding of the collective influences and identify common patterns, we consolidated the nodes from the individual influence maps based on their alignment with specific SCCT constructs. This involved examining the content of all nodes across all diagrams and combining similar quotations or summarized factors, ensuring that each merged element accurately represented a shared influence within the SCCT framework. This iterative synthesis resulted in the creation of comprehensive collections of nodes for each SCCT construct (e.g., Learning Experiences). These nodes and links were then further refined, and nuanced themes and patterns were identified and subsequently labeled as emergent subcategories within each SCCT construct. This process allowed us to systematically group factors according to their theoretical underpinnings in SCCT, leveraging its prominence as a framework to synthesize the individual student data. These emergent subcategories provided a more granular and context-specific understanding of the factors influencing student interest in each method (theoretical and computational physics). For a more detailed visual representation and explanation of these steps, readers are referred to [5]. In our qualitative analysis, a consensus was reached through discussion between multiple researchers, making an inter-rater reliability score less applicable.

IV. RESULTS

This section presents results related to three SCCT constructs: learning experiences, self-efficacy, and outcome expectations. Within each SCCT construct, findings are organized by emergent subcategories that reflect the range of student responses with respect to computation and theory.

A. Learning Experiences Shaping High-Interest in Theory & Computation

Learning experiences, which are divided into multiple subcategories, play significant roles in shaping students' interest in theoretical and computational physics.

Self-directed learning refers to how engaging with self-study materials, such as online videos, recent physics publications, and coding tutorials, shapes students' interest in theoretical and computational physics. For theoretical physics, several students highlighted the role of online video platforms, especially YouTube, in sparking and sustaining their interest. Dominic (Y1, T-8.5) noted that pre-college exposure to videos explaining thought experiments by prominent physicists like Einstein was a significant learning experience that affected his interest in theory. He also connected early exposure to physics content with the development of his theoretical interests. He said, "The channel PBS Space Time, they also do videos covering recent scientific papers, which can be pretty interesting. Apparently, there was recently someone published papers about the black hole information paradox that involves virtual wormholes, which is like, the kind of crazy thing that's like, Okay, I need to know what's going on here." His excitement about complex ideas shows how early exposure sparked his curiosity. Jamie (Y1, T-9) also acknowledged the potential influence of engaging physics-related content found on YouTube prior to college. Among students with a high interest in computational physics, two students mentioned self-directed learning as an influence on their interest. For instance, Sean (Y4, C-8) learned MATLAB through self-directed efforts, he said, "I had to basically learn all of MATLAB, which is amazing because MATLAB is so much pretty useful."

Pre-college and high school coursework was mentioned by both group of students with a high interest in theoretical and computational physics. Students who were interested in theory emphasized the role of early math experiences, especially calculus, in shaping their interest and readiness for theoretical physics. For instance, Kayla (Y2, T-10) credited her positive experience and strength in calculus as a key foundation for engaging with the mathematical demands of theoretical physics. Some high-interest computational students mentioned taking programming courses prior to college. For example, Rebecca (Y4, C-9) stated,"I had AP computer science. Then I had a computational class, it was physics-specific and that was really fun. I like that a lot. So I continue taking more and more computational physics based classes."

Core college coursework was important in building a strong foundation in theoretical and computational physics. Three students mentioned this subcategory a few times as a factor influencing their interest in theory, while two students mentioned it in computation. Students described how these courses developed critical thinking skills, improved problem-solving abilities, and provided a deeper understanding of core concepts. For instance, Dave (Y4, T-8) interested in theoretical physics, stating, "I think what really influenced my opinion was definitely talking to having classes and talking with [Name of the professor] suddenly realize that what they did had such an impact. I really enjoyed classical mechanics and to do everything theoretically made me really, really enjoy it... All [my professor] does is theory and he's very humble about what he knows". Dave's interest grew through his engagement with core classes, particularly under the guidance of one of his professor. Among students interested in theory, they usually mentioned upper-division courses. Among students interested in computation, they usually mentioned introductory computational courses and lab-based classes, such as Sean (Y4, C-8) who emphasized the value of college courses like "Intro to Computational Physics and Electronic Measurements and Modern Lab." He mentioned physics courses focused on building skills in numerical methods, simulation, and data analysis.

High school teachers and mentorship highlights how mentors and teachers can inspire interest in theoretical and computational physics by providing guidance and support.

Four students (1 computational and 3 theory) mentioned high school teachers, and four students (2 computational and 2 theory) mentioned mentors and college instructors as influential factors for their interest formation in theory and computation. Rebecca (Y4, C-9) elaborated on the impact of their high school physics teachers, stating, “physics was a thing. But it wasn’t as interesting to me because I was going to go into computer science. Then I had the physics teachers who were physics majors in their college... And that made me want to do that. So it kind of make physics seem cooler.” This shows how an enthusiastic physics teacher inspired a student to combine their pre-existing computational interests with physics and to pursue physics as a degree. Dave (Y4, T-8) shared how his research mentor directed him to credible resources such as “MIT books because I was looking at weird YouTube videos”, encouraging more structured learning approach. Saba (Y3, C-10) said in her computational research project, she received “A lot of support from my professors and my lab mates. They’re always so willing to help. They really want to help me as a newbie.”

Research and applications examines how early research and project experiences can spark interest in theoretical and computational physics. Two high-theory students (Dave: Y4 and Kayla: Y2) and three high-computation students (Saba: Y3, Sean: Y4, and Rebecca: Y4) reported having research experiences. Research experiences were more prevalent in later undergraduate years. Theoretical research often involved mathematical derivations and building mathematical models, as noted by Kayla (Y2, T-10) who derived equations, and Dave (Y4, T-8), who enjoyed “model-making.” In contrast, computational research experiences primarily involved programming, recording data, and using coding software, such as R, to analyze data. Rebecca’s (Y4, C-9) research involved writing code to analyze large data sets and conduct on statistical analyses.

B. Self-efficacy of High Interest Students

High self-efficacy in theoretical or computational physics often reflected confidence in specific skills, like understanding concepts or coding, and was linked to stronger career interest. In contrast, other studies found that low self-efficacy reduced interest and engagement.

Beliefs in mathematical ability captures how students’ confidence in their math skills influenced their decision to pursue theoretical physics. For example, Brian (Y1, T-8) demonstrated self-efficacy in theoretical physics, stating he believes success depends on his math skills, highlighting this as a crucial enabler or barrier to his engagement. Kayla (Y2, T-10) also demonstrated strong self-efficacy rooted in her confidence with mathematics. She found satisfaction in understanding and applying “rule sets,” viewing math as inherently enjoyable because the math gives answers that can be clearly verified. Despite occasional “self-doubt,” Kayla trusts her ability to adopt the necessary mathematical viewpoints for problem-solving, seeing it as a reliable tool for understanding complex physics concepts.

Beliefs in understanding, learning, and success reflects students’ perceptions of their ability to grasp complex concepts, learn new tools, solve problems, and ultimately succeed in theoretical or computational physics. While generally confident, students often added caveats. For instance, Dominic (Y1, T-8.5) felt capable of learning what’s needed for future work and Kayla (Y2, T-10)’s confidence stemmed from a ability for math and applying physics rules. Jamie (Y1, T-9) emphasized the importance of consistent, day-to-day effort as “most of the battle” for class success. Julie (Y1, T-8) expressed nervousness about future courses, stating a strong desire to “understand and learn these concepts” and emphasizing, “I don’t want to fail.” Saba (Y3, C-10) felt confident in mastering Python but faced challenges with tools like Fortran and Linux. She expressed general problem-solving confidence, believing she could “definitely try and figure it out.” These responses reveal a spectrum from broad confidence to more cautious, task-specific beliefs about overcoming challenges.

Motivation and happiness highlights how students’ self-efficacy was closely tied to their motivation and sense of fulfillment in pursuing their chosen physics specialization. Students’ confidence in their abilities directly impacted their drive and satisfaction, which often manifested as a profound curiosity that motivated their engagement with their chosen physics specialization. For instance, Kayla (Y2, T-10) said,“It’s a curiosity thing. I want to know why things happened this way.” Kennedy (Y1, C-9), for example, felt most confident in computational physics, aligning with her personal interests, which in turn boosted her self-efficacy and enjoyment in that specialization.

Challenges of self-directed learning reflects the difficulties students encountered when independently studying complex concepts, often affecting their confidence and self-efficacy. Sean (Y4, C-8) expressed his frustration with self-learning in computational physics, stating, “It’s very frustrating to do it on your own when you don’t understand anything.” He found computational work particularly inaccessible through self-study, feeling “lost completely" even after consulting resources like DataCamp and Khan Academy. Sean felt he could teach himself theoretical physics but needed guidance for computational physics, highlighting how the perceived need for external support can limit self-efficacy and engagement. For Kayla (T-10), the challenges of self-learning in theoretical physics related to challenges deriving equation. She described the process of deriving equations as “very very stressful in terms of just algebraically abusing them into the shape you want.” Even for students who were interested in theory, the independent mastery of complex mathematical derivations was challenging.

C. Outcome Expectations of High-Interest Students

Within the SCCT framework, outcome expectations are beliefs about a career path that influence the development of career interests. The major subcategories of outcome expectations (described below) are the same as those in prior work about students with low interest in theoretical and computational physics [5].

Disciplinary ideas reveal distinct perspectives on the nature and focus of theoretical versus computational specializations in physics. Theoretical work was sometimes perceived as abstract and less tangible. Julie (Y1, T-8) noted a dislike for not being able to "really see it actually happen" and feeling "not entirely sure"," suggesting a challenge with the abstract nature of theoretical concepts." In contrast, computational physics was emphasized for its practical importance and essential skill set. Rebecca (Y4, C-9) enjoyed the coding aspect of computational physics, finding it "very fun." Saba (Y3, C-10) considered computational as a crucial "pillar" alongside theoretical and experimental work. Sean (Y4, C-8) viewed programming as a necessary skill for any science or engineering career, stating, "I can't do science and not expect to not know how to program." These examples highlight that computational specialization is highly practical, integral to data-driven research, and relies on core programming skills.

Practices refer to daily activities in each specialization. Theoretical physics was seen as math-heavy and thought-driven. Kayla (Y2, T-10) enjoyed the math focus, while Jamie (Y1, T-9) described work in theory as "just thinking," emphasizing its abstract, cognitive nature. Dave (Y4, T-8) liked theory but missed hands-on experiments and saw theory as "doing math on a whiteboard" or "grinding calculations" alone. Computational physics was seen as focused on coding, debugging, and quick results. Sean (Y4, C-8) disliked sitting at a computer all day, but Rebecca (Y4, C-9) and Kennedy (Y1, C-9) enjoyed coding, problem-solving, and visualizing data. Saba (Y3, C-10) described it as "collecting data and finding patterns." Rebecca (Y4, C-9) valued computation's immediate results and saw computational errors as simpler to fix than messy real-world experimental issues, appreciating the controlled, debuggable nature of computational work.

Professional and personal life reflects on the lifestyle and workplace environment associated with each method specialization. Theoretical physics was often tied to academia and seen as abstract and solitary. Kayla (Y2, T-10) highlighted her "preference for work environments with fewer interpersonal interactions." Brian (Y1, T-8) expected theory to lead to an academic, rather than industry, path due to its lack of immediate applications. In contrast, computational physics was framed around practices. Sean (Y4, C-8) who rated computation high, still disliked the idea of sitting at a computer all day like a software engineer.

V. CONCLUSIONS

This study explored how students developed high interest in theoretical and computational physics using the Social Cognitive Career Theory (SCCT) framework. Our findings suggest that students' interests are shaped by an interplay of learning experiences, outcome expectations, and self-efficacy. For students with high interest in theoretical physics, positive influences often included early exposure to engaging content, supportive mentors, inspiring high school teachers, and well-designed coursework that fostered intellectual satisfaction and skill development. This aligns with a study by the American Institute of Physics that shows how early experiences, particularly high school physics classes and teachers, are a major influence for students to pursue a physics degree [13]. Students frequently perceived theoretical physics as difficult and mathematically intensive. However, their interest was reinforced when they successfully understood the material and solved related problems. These experiences built confidence and sparked curiosity, particularly when students felt capable of mastering mathematical reasoning. In contrast, prior analysis of students with a low interest in theory found that theoretical physics was often perceived as irrelevant, isolating, or overly abstract. Negative factors included poorly taught theory courses, and low self-efficacy, especially when students struggled with abstract and mathematical thinking.

Students with strong interest in computational physics often viewed it as a practical and essential skill for their future careers. Students often described their learning experiences in computational physics as similar to those in theoretical physics. Positive outcome expectations for computational physics included the ability to get immediate results, the ability to visualize outcomes, and clear connections between computation and experiments, all of which increased interest and engagement. Conversely, the previous study on low interest in computation found that computational work was viewed as tedious, overly screen-focused (rather than hands-on), and lacking in interpersonal connections. Negative factors included frustrating coding experiences and low self-efficacy, particularly when students felt lost without direct guidance. These findings show that varied learning experiences shape self-efficacy, outcome expectations, and career interests. To support diverse paths and sustained interest, educators should offer early exposure, mentorship, and clear links between coursework and careers.

There are some limitations in this study. First, the sample size was relatively small, with 6 students having high interest in theory and 4 in computation. Additionally, half of participants in this analysis were in their first year of academic study, which might limit the generalizability of the findings to students at later academic stages. One possible explanation for the larger sample of first-year students is that interest in theory starts out high for a large fraction of physics majors, but decreases as students progress through the curriculum and struggle (decreasing self-efficacy) or are exposed to other areas of physics.

Future work could expand the study to a larger and more diverse student sample, add an analysis of interest formation in experimental physics, and include longitudinal tracking of career paths. Research could also examine teaching strategies that boost interest and self-efficacy in theoretical and computational physics, especially where self-learning is difficult.
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