Evaluating Students' Attitudes and Learning in an Undergraduate Particle Physics Online Course

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As part of a National Science Foundation-funded initiative to broaden career pathways for physics majors at Hispanic-Serving Institutions (HSIs), we developed and implemented an online particle physics course through the CSU Fully Online system. The course integrates active learning strategies—including pre-recorded lectures, weekly conceptual assessments, structured office hours, and research term papers. Students are selected from this course for further engagement through summer research at national and international labs such as CERN (European Organization for Nuclear Research). This paper presents preliminary findings from the first implementation, examining changes in students' self-efficacy, physics identity, and interest over the semester, as well as the relationship between these affective dimensions and performance on pre and post-assessment questions. Pre/post survey results revealed stable levels of interest, some positive shifts in identity, and a significant correlation between post-course identity and post-assessment performance. These preliminary results offer insight into how online physics courses can support both affective development and learning.

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I. INTRODUCTION

Many public undergraduate institutions like the California State Universities (CSUs) face systemic barriers to equitable access to upper-division coursework and research, due to limited resources and faculty. As a result, physics majors at these schools may be less prepared or less confident in pursuing advanced study or research careers compared to their peers at R1 institutions [1]. As a step toward offering high-impact educational experiences to students at CSU and other community colleges, we offered an undergraduate particle physics course via CSU Fully online, a system that is open to all CSUs as well as collaborating community colleges.

The course is part of an NSF HSI project between CSU Fresno and Cal Poly Pomona, which also supports selected students for summer internships at CERN (European Organization for Nuclear Research). Physics education research to investigate students' learning in particle physics, as well as a couple of other online courses to add to the variety of electives, are also part of this project. This paper is focused on the " Introduction to Particle Physics" course that we offer every fall semester for the duration of the grant.

Online courses, including MOOCs, offer scalable access and flexible participation opportunities for diverse learners, but continue to face challenges related to learner engagement, completion rates, and the alignment of course design with student motivation and needs [2-4]. Research on active learning in online courses is limited, likely due to the challenges of implementing interactive pedagogies in virtual settings. As Dixson [5] noted, no single activity guarantees higher engagement online. However, using multiple communication channels and incorporating meaningful student-student and student-instructor interactions can enhance engagement.

The course, titled "Introduction to Particle Physics" (PHYS 163), was delivered via CSU Fully Online and accessible to students at all 14 partner HSI institutions (including 11 CSUs and 3 community colleges). Due to the logistic limitation in holding synchronous sessions for students, we post asynchronous lecture videos accompanied by a variety of other supporting elements informed by active learning including Just-in-Time Teaching (JiTT) [6] with pre and post questions [7]; synchronous office hours with structured think-pair-share questions and tutorial like activities [8]; term paper on cutting-edge research topics; online discussion forum which provides reading resources and materials for the term paper [9].

Self-efficacy, physics identity, and interest in physics are key affective constructs shown to correlate with students' course performance and longer-term decisions to persist in physics [14–19]. These beliefs—about one's ability to succeed, sense of belonging in the physics community, and intrinsic motivation—play a particularly important role for students from groups historically underrepresented in physics, such as those attending Hispanic-Serving Institutions (HSIs), where structural and social barriers may further challenge persistence. In this project, we administered pre and post-course surveys in an online particle physics course to measure these three constructs. Given the project's goal of broadening access to cutting-edge physics content and research experiences—especially for students from HSIs—understanding the affective impacts of the course is critical to evaluating its role in promoting equity and supporting students' aspirations in physics.

This paper presents preliminary findings from our initial implementation of PHYS 163 in Fall 2024. Our aim is twofold, guided by the following research questions:
(1) How do students' self-efficacy, physics identity, and interest in physics change over the duration of an online particle physics course?
(2) To what extent are students' affective measures related to their performance on weekly pre and post assessments? Our findings provide insight into the affective and cognitive trajectories of students in an online physics course and offer implications for future course design and institutional practices that seek to broaden access in physics.

II. THEORETICAL BACKGROUND

Students' affective experiences in physics—such as how they see themselves in the discipline, their confidence in succeeding, and their interest in the subject can predict persistence and performance in STEM [14-19].

We focus on three interrelated constructs: self-efficacy, physics identity, and physics interest, measured by items from previously published surveys where validity and reliability were tested. **Self-efficacy** (belief in one's ability to succeed) was measured using items adapted from the Physics Self-Efficacy Questionnaire [13]. **Physics identity** was assessed using items adapted from valid and reliable surveys [11,14,17, 20], capturing both internal recognition ("I see myself as a physics person") and social recognition by peers, friends, instructors, and family (which was labeled as "physics perceived recognition" in Li's article) . **Interest** items—such as "I wonder about how physics works" and "I am curious about recent physics discoveries"—were drawn from Li & Singh [11], and reflect both intrinsic curiosity and disciplinary engagement.

Although the course was not specifically structured to target these constructs, it incorporated active learning elements—such as pre/post conceptual questions, discussion-based office hours, and term papers—that could support affective development. In this study, we examine how students' development of self-efficacy, identity, and interest is supported and maintained in such an online course, and how these dimensions relate to their conceptual learning outcomes.

Pre and post assessment questions are widely used in physics education research to measure student learning and reasoning. For example, the University of Washington Tutorials [21] use them to assess conceptual change in introductory physics, while course transformation efforts at CU Boulder [22] apply them at the upper-division level to evaluate instructional impact. These assessments help capture learning gains and identify persistent difficulties beyond what grades alone reveal. In our study, we write weekly pre/post questions to gather insights into students' reasoning and measure their learning gains each week.

III. METHODS

The participating institutions included 11 CSU campuses and 3 community colleges, with final enrollment consisting of 31 students from 8 CSUs and 1 community college. The course was taught by a physics faculty member from Fresno State, an experimental particle physicist with extensive experience teaching similar courses. The lead author, a physics education researcher and faculty member, led the curriculum redesign and research component, in collaboration with a co-PI (a theoretical physicist) who contributed to course material development.

Each week, students were assigned two pre-recorded lecture videos and completed pre/post conceptual assessment (each contains 2–4 questions) via Canvas. These questions were co-developed by the lead author and co-PI and finalized with the instructor; sample questions are provided in the supplemental documents [23]. Most are multiple choice questions with only a couple free response "explain your reasoning" questions, which were scored by hand by the lead author. Students received full participation credit and were encouraged weekly to respond thoughtfully based on their current understanding.

Due to scheduling constraints across campuses, the course was delivered asynchronously. To encourage interaction, the structure followed a flipped format: students watched lectures independently and were invited to two hours of scheduled synchronous office hours each week (not mandatory), featuring a concept question and a tutorial-style activity. Students also completed three homework sets, a midterm, and a final exam proctored in person by faculty liaisons from each campus.

At the end of the semester, students submitted a 10-page term paper on a particle physics topic of their choice, aimed at encouraging deeper engagement with modern research and topics relevant to institutions like CERN or Fermilab. Topics were selected on a first-come, first-served basis and shared via class email. Prompts included the topic's significance, recent developments, and ongoing or future research efforts.

Separate from pre- and post- assessment that focused on measuring students' understanding of the content, three surveys (measuring students' perception and affect) were administered electronically at the beginning, middle, and end of the semester. The pre- and post-surveys included measures of self-efficacy, physics identity, and interest. The mid-semester survey gathered feedback on course structure and the usefulness of components, and was administered separately from the end-of-semester survey to reduce the time burden in one survey. To reduce social desirability bias, students were informed that the course instructor would not see their survey responses, and that extra credit (0.5 points per survey) would be awarded regardless of their consent to participate. A member of the research team unaffiliated with course instruction introduced the study and managed all research-related tasks.

IV. RESULTS

Students' perceived usefulness:

In the mid-semester survey (N = 19), students ranked the top three course components most useful for their learning. Watching the recorded lectures was cited by 89% of students, followed by completing homework sets (63%) and engaging with weekly pre/post concept questions (53%). Reading the textbook and collaborating with classmates were each selected by about one-third of respondents (37% and 36%, respectively), while only 21% ranked office hours among their top three. These responses suggest that asynchronous components were most valued, possibly due to the flexibility they offer in an online course. In contrast, lower ratings for office hours and peer collaboration may reflect challenges with real-time engagement. (Note: The term paper was excluded from the survey as it was not yet due.) These insights can inform improvements such as increasing structured peer interaction and promoting office hour participation.

Self-efficacy, Physics Identity and Physics Interest:

In the pre and post surveys (N=24 and 23 respectively), students were given statements corresponding to the measures of self-efficacy, physics identity, and interest. Full survey items for self-efficacy, interest, and physics identity are provided in the supplemental document [23]. Students rated each statement using a 5-point Likert scale. McNemar's test [24] was conducted on each item across self-efficacy, physics identity, and physics interest, collapsing responses into "Agree" vs. "Not agree" (including neutral and all disagreement). No items showed statistically significant pre-post shifts.

Self-efficacy was measured using five statements (SE1–SE5) [23] related to problem-solving confidence, goal achievement, exam readiness, and general physics self-belief, rated on a 5-point Likert scale. Pre/post results (shown in Fig.1) did not show statistically significant changes. Most response distributions remained stable, suggesting consistent self-perceived competence. However, SE3 ("I will remain calm in my physics exam...") declined from 73% to 52% agreement, hinting that students may have reassessed their confidence after taking course assessments. Future iterations may benefit from added support for exam preparation and confidence-building.

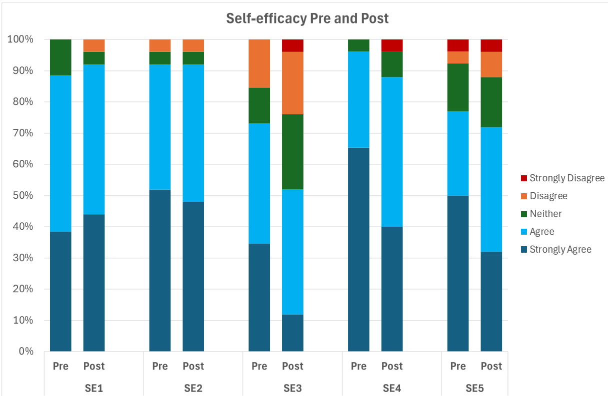

FIGURE 1. Pre- and post-survey responses (Self-efficacy)

The **physics identity** measure included five items focused on self-perception and perception by others. Results are presented in Figure 2. Student responses to the five physics identity items showed no statistically significant changes from pre to post-survey. However, several positive trends were observed. Agreement with the statement "My friends see me as a physics person" increased from 81% to 96%, and the percentage of students who disagreed that "My parents see me as a physics person" dropped from 15% to 0%. While these shifts were not statistically significant, they may reflect educationally meaningful improvements in students' sense of recognition and belonging in physics. Prior research suggests that positive identity development and family support are important for sustaining interest and persistence in STEM fields [25,26].

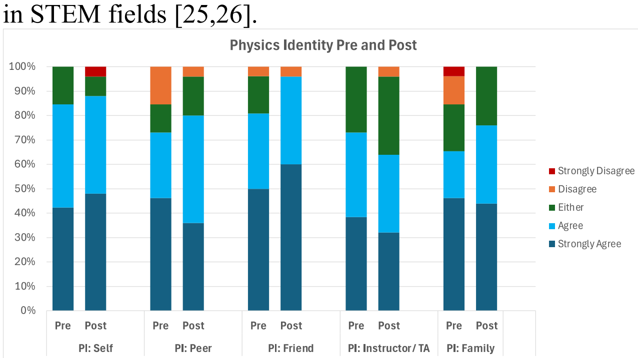

FIGURE2. Pre- and post-survey responses (Physics Identity)

The **physics interest** measure included four items about their interest towards physics in general [23]. Items were rated on 5-point scales appropriate to each question, such as frequency ("Never" (scale 1) to "Every day"(scale 5)) or agreement ("Strongly Disagree" (scale 1) to "Strongly Agree" (scale 5)). Student responses reflected consistently high levels of physics interest throughout the course (see Figure 3). For example, all students rated physics as either "interesting" or "very interesting," and nearly all reported wondering about how physics works on a daily or near-daily basis in both pre- and post-surveys. Agreement with the statement "I want to know everything I can about physics" remained stable at around 92%. The only notable shift was a slight decrease in agreement with "I am curious about recent physics discoveries," which declined from 92% to 80%. While these changes were not statistically significant, they may reflect a normalization of excitement as students became more familiar with the material. In future iterations of the course, we may better support students in maintaining curiosity about cutting-edge topics—potentially by strengthening the structure and guidance for the final term paper assignment. While students reported consistently high levels of interest in physics on both pre- and post-surveys—introducing a potential ceiling effect—this stability is itself notable. Prior studies have documented declines in student interest even in reformed physics courses [27] with high learning gains, so the sustained high interest observed here may reflect a meaningful educational outcome.

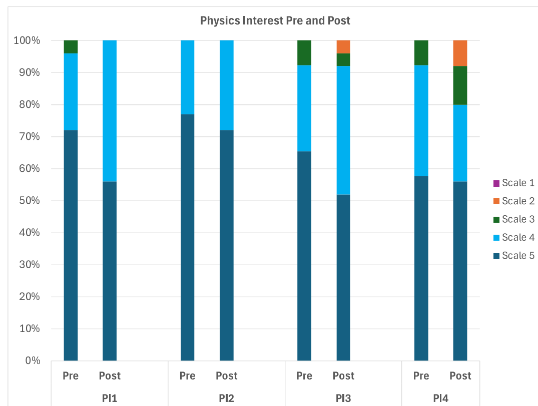

FIGURE3. Pre- and post-survey responses (Physics Interest)

Correlation with learning:

To explore the relationship between students' affective measures and their conceptual understanding, we computed Spearman's rank correlation coefficients (ρ) [28] between each affective construct—self-efficacy, physics identity, and physics interest—and students' performance on conceptual assessments. Affective measures were collected through pre- and post-course surveys using composite scores derived from multiple Likert-scale items (e.g. 5 is for strongly agree). Assessment scores were calculated as the average of students' responses to weekly conceptual questions across the term. Given the ordinal nature of survey data and the presence of tied ranks, Spearman's ρ was used as a nonparametric measure of association.

	Spearman's rank correlation coefficients (ρ)	Pre Assessment Score	Post Assessment Score
Pre (N=24)	Self-efficacy	0.09	0.22
	Physics Identity	0.29	0.17
	Interest	0.17	–0.03
Post (N=23)	Self-efficacy	0.29	0.27
	Physics Identity	0.20	0.47
	Interest	0.07	0.35

TABLE I. Spearman's correlation between affective measures and pre and post conceptual assessment scores.

Our analyses examined how affective measures related to students' conceptual scores. Pre-survey measures showed weak and inconsistent correlations. In contrast, several post-survey measures—particularly physics identity—exhibited larger positive correlations with post-assessment performance, though none were statistically significant after correcting for multiple comparisons. For example, the correlation between post-course physics identity and post score was $\rho = 0.47$, but did not reach statistical significance. Other post-survey constructs such as interest ($\rho = 0.35$) and self-efficacy ($\rho = 0.27$) were also positively correlated with post scores. While modest and not statistically significant, these associations suggest a more consistent directional relationship between students' end-of-course attitudes and their performance compared to pre-survey measures. These results align with prior literature emphasizing the role of affective dimensions—particularly identity—in supporting learning and persistence in physics. While causality cannot be inferred from these data, the findings raise the possibility that students who developed a stronger physics identity during the course may have engaged more deeply with the material or felt more confident in their learning. This supports the idea that affective engagement and identity development may contribute to student success, especially in online environments serving students at HSIs.

Although not the main focus of this paper, we briefly address the validity of the weekly pre- and post-assessment questions used to gauge conceptual understanding. Pre-scores moderately correlated with midterm ($r = 0.51$), final exam ($r = 0.37$), and final grade ($r = 0.38$), suggesting alignment with course-level objectives. Post-scores showed similar patterns. These results provide preliminary evidence of criterion-related validity and motivate future work toward building research-based assessment questions.

V. CONCLUSIONS AND DISCUSSIONS

Our findings suggest that an online upper-division particle physics course can support affective development and, to some extent, conceptual learning for students at Hispanic-Serving Institutions. Although shifts in self-efficacy, physics identity, and interest were not statistically significant, several trends—particularly in identity-related items such as recognition by peers and family—appear educationally meaningful. Given the small sample size, these results should be interpreted cautiously. However, the absence of a significant decline in self-efficacy is notable, as such declines are common even in active-learning courses (Nissen & Shemwell, 2016; Dou et al., 2016), suggesting that our course design may have may have helped sustain students' self-efficacy.

This interpretation aligns with prior work highlighting the importance of physics identity in supporting persistence and confidence. In our data, post-course physics identity was the only affective measure significantly correlated with post-course conceptual scores, pointing to identity as a potentially stronger predictor of learning outcomes than self-efficacy or interest in this context. While we do not claim causality, these findings underscore the importance of designing online physics courses that not only deliver content but also affirm students' sense of belonging in the physics community.

From an instructional perspective, the results indicate opportunities to strengthen how active learning is supported online. Although elements like recorded lectures and pre/post questions were rated highly by students, office hours and peer interaction were ranked as less useful—possibly due to scheduling limitations in a fully asynchronous setting. In future iterations, we plan to refine the structure of synchronous activities and explore ways to better scaffold research-based writing tasks like the term paper, particularly to sustain curiosity around modern physics topics. This study did not examine differences across student subgroups such as gender or ethnicity, due to insufficient sample sizes within those categories. As we continue collecting data in future iterations of the course, we aim to explore these dimensions to better understand how students from diverse backgrounds experience and respond to the curriculum. While this paper focuses on quantitative outcomes, preliminary student interviews conducted by an external evaluator suggest the course may foster a sense of belonging through its inclusive structure and support for engagement. In future work, we plan to incorporate additional interviews and open-ended surveys to further investigate students' experiences and conceptual development.

These preliminary findings demonstrate that even a first-time implementation of an online particle physics course can create meaningful engagement in affective domains. Future work will expand on these results with larger cohorts from multiple semesters, improved curriculum design, and refined assessments to further investigate how online instruction can support inclusive excellence in physics education.

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