

Astronomy identity framework for undergraduate students and researchersZachary Richards¹

Department of Earth and Physical Sciences, York College, *City University of New York*,
94-20 Guy R. Brewer Boulevard, Jamaica, New York 11451, USA
and Institute for STEM Education, *Stony Brook University*, 092 Life Sciences,
Stony Brook, New York 11794-5233, USA

Angela M. Kelly^{2*}

Department of Physics and Astronomy and Institute for STEM Education, *Stony Brook University*,
092 Life Sciences, Stony Brook, New York 11794-5233, USA



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This research was a qualitative transcendental phenomenological exploration of astronomy identity formation among astronomy majors and physics majors engaged in astronomy research. Participants ($N = 10$), all of whom identified with traditionally marginalized groups in astronomy, were recruited from two large universities in New York state at different stages in their undergraduate careers. *Social cognitive career theory* and several science, technology, engineering, and mathematics identity frameworks conceptually guided the analysis of astronomy identity for undergraduate majors and undergraduate astronomy researchers by exploring participants' interest in, choice to study, and persistence in astronomy. Themes related to astronomy interest were popular culture and directly observing astronomical phenomena, while astronomy choice and persistence were facilitated by experiences in introductory coursework, recognition from faculty, and socializing with peers. The emergent astronomy identity framework was characterized by six distinct yet interrelated constructs: (1) interest in astronomy, typically rooted in observing naturally occurring phenomena and engaging with popular culture; (2) recognition from peers, experts, and families; (3) peer socialization about shared astronomy experiences; (4) competence or the belief one can do the work of an astronomer; (5) sense of belonging within the astronomical community; and (6) astronomy career expectations. Findings from this research provide insights on factors that influence undergraduates in four-year colleges to study astronomy, and how students' past experiences may lead to a natural interest in astronomy that may be fostered in secondary and postsecondary contexts. Implications suggest departments and institutions may facilitate the accessibility of astronomy at the collegiate level by promoting a more inclusive astronomy community, fostering interactions with astronomy faculty and graduate students, providing opportunities for undergraduate research, and communicating expectancy for astronomy-related future careers.

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Identity frameworks have been defined and applied in prior research to understand how and why students choose particular academic and career pathways in science, technology, engineering, and mathematics (STEM) [1,2]. Although some work has explored identity formation in STEM disciplines such as physics [3,4], few have examined astronomy specifically. Astronomy and physics are

two distinct disciplines that are interwoven and difficult to separate, as evidenced by many higher education institutions combining them into one academic department [5]. Astronomy examines celestial bodies and the universe, while physics offers theoretical explanations of observable astronomical phenomena. There are similarities and differences between physics and astronomy disciplines and their respective epistemological approaches. With physics, students are often able to interact with physical systems in their natural world while exerting experimental control over many of the variables they study. Conversely, astronomy is largely an observational science, although testable physics concepts may explain celestial phenomena that are simulated and modeled. Students cannot physically interact with observed systems, but they can readily engage with celestial bodies by gazing at the sky. Those who study

*Contact author: angela.kelly@stonybrook.edu

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astronomy often rely upon large-scale datasets and simulations to conduct their research. These fundamental differences between physics and astronomy disciplines may necessitate a unique identity framework for understanding the development of astronomy self-concept and career aspiration formation.

Astronomy study is far less prevalent than physics study [5], although these fields are often combined when considering degree attainment. In many cases, students who wish to pursue astronomy either major in physics, due to limited availability of an astronomy major, or enroll in a combined physics and astronomy program. In the 2022–2023 academic year, 934 bachelor's degrees were awarded in astronomy across combined and stand-alone astronomy departments in the United States, compared to 8295 bachelor's degrees in physics [5]. Some demographic disparities persist in astronomy enrollment. Between 2017 and 2021, 38% of all astronomy bachelor's degrees were awarded to women, compared to 28% in physics [6]. Additionally, 14% and 15% of degrees were awarded to students from underrepresented ethnic groups in astronomy and physics, respectively [7].

Since the number of astronomy majors in U.S. higher education is relatively low, most astronomy education research has focused on students in general education astronomy courses [8,9], which typically enroll nonscience majors [10]. Research in astronomy major choice and persistence at the undergraduate level has been limited [11,12]. This is consequential since the employment of physicists and astronomers is expected to grow 7% from 2023 to 2033, which is faster than most workforce sectors [13]. The median wage for astronomers in 2024 was \$132,170, more than double the median wage of \$49,500 for all U.S. workers [13], which suggests the choice of a career in astronomy is a pathway for socioeconomic advancement for traditionally marginalized students. Although there has been significant research on the STEM identity of undergraduate students ([1–4,14–17]), there has been minimal research on astronomy identity.

This work seeks to address this void in astronomy education research with a sample of ten demographically diverse undergraduates who majored or performed research in astronomy during the 2022–2023 academic year. Given the inherent differences between physics and astronomy study, the development of an astronomy identity framework by adapting prior STEM identity frameworks may provide insights leading to increased recruitment and retention in this discipline.

II. LITERATURE REVIEW

A. STEM identity

Although astronomy identity has not been addressed substantively in previous literature, there has been research on factors contributing to STEM identity. For example, the

work of Hazari *et al.* [14] presents a physics identity framework that includes factors such as physics performance, competence, recognition from others, and interest. Experiential aspects include class participation, teacher encouragement, and regular discussions of current science topics, which have been shown to positively affect physics identity and STEM identity in general [14]. This framework is rooted in Carlone and Johnson's [18] science identity framework, which consists of performance, recognition, and competence. The physics identity framework [14] expanded upon this by explicitly identifying interest as a construct, although this was implied in Carlone and Johnson's framework [18].

Career expectations have also been shown to relate to STEM identity. These career expectations include skills, experiences, and/or outcomes related to a desirable vocation [19]. In a study exploring 15,847 responses from the *Outreach Programs and Science Career Intentions* survey, students who intrinsically prioritized career outcomes such as valuing the skills they developed and having an exciting job within physics increased physics identity [19]. Performing research is a common career expectation as it allows students to develop the skills of a professional astronomer. Institutions may encourage STEM students to engage in undergraduate research, but it is often not required. Students who participate in undergraduate research often build a sense of STEM identity [17], which may change over time through an increased sense of agency and ownership [18].

1. Gender- and ethnicity-based identity studies

Research has found significant gender disparities in STEM identity, with young women more likely to experience less self-efficacy and self-concept [20,21]. External factors such as recognition and validation have been identified as more impactful for women in high school, undergraduate, and graduate STEM when compared to men [17,22]. For women, interest may develop because they received recognition from both teachers and parents [23,24], which may influence their performance and sense of competence [25]. Inclusive teaching practices and active teacher recognition have been identified as powerful strategies for building a sense of physics identity among women [26]. One such strategy is explicitly addressing gender-based physics underrepresentation in high school physics classrooms—this communicates a sense of caring and encouragement [14]. The intersectional physics identities of women of color and LGBTQ+ students have also been explored, with research finding they strengthen identity when they are allowed to fully be themselves and they do not need to hide their sexual orientation to be a part of their communities [27].

Physics identity research has also been explored for racialized minority groups. Hyater-Adams *et al.* [15,16] devised a critical physics identity framework for

African-American physics students. It built upon Hazari *et al.*'s [14] physics identity framework, noting that some ethnic and gender minorities tend to have more negative experiences in physics and experience higher levels of imposter syndrome [15,16]. Research on the persistence of graduate students in physics and astronomy has noted imposter syndrome to be a cause of attrition in the astronomical field for both women and men [12]. Research has also found that African-American students are less likely to participate in activities that contribute to building a sense of physics identity [28], which is consequential since participation in astronomy outreach programs has the potential to increase African-American students' sense of astronomy identity [29].

2. Astronomy identity in younger students

Although research on astronomy identity is limited, a recent study sought to develop an astronomy identity framework for middle school-aged students [30], identifying four constructs: (1) interest; (2) recognizing the utility value of astronomy; (3) confidence in performing astronomy tasks; and (4) astronomy conceptual knowledge. This framework noted that girls tend to experience an increased sense of astronomy identity that originates from interest, while overall astronomy identity tends to decrease between fifth and ninth grades. Interest is often developed by engaging in amateur astronomy and observing natural phenomena [30]. This may translate to older students in related fields who participate in amateur astronomy.

B. Internal motivations for studying physics and astronomy

Students often decide they want to study physics before college because they have a passion for physics and/or an emotional connection to it [31,32]. Since astronomy is often not required in high school [33], students may take it as an elective or learn some astronomy topics in their physics or Earth science courses. Research has found that students are generally interested in astronomy during elementary and middle school, yet they tend to lose interest by the time they finish high school [34,35]. Students may build interest in physics and astronomy through informal outreach activities [28,34], and this interest has been correlated to identity development [14]. Some informal activities that affect physics identity are observing stars, tinkering, and talking science with other people [28]. For example, students who observed stars in an astronomy club were 2.7 times more likely to be interested in an astronomy career by the end of high school [34]. Underrepresented groups may be less likely to develop physical science identity because it is often thought that one must be gifted mathematically to study this field, which negatively impacts their participation [36,37].

While many students decide to study physics and astronomy before entering college [31,32], some decide

after matriculating in college. Introductory level courses may inspire students to pursue the physics and/or astronomy major [38]. McCormick *et al.* [39] interviewed five female graduate students in physics and astronomy about what influenced their academic path. The participants indicated their interest increased during their introductory physics or astronomy classes, noting the influence of skilled pedagogy [38,39].

Research and laboratory experiences in the classroom may have an impact on a student's astronomy identity, fostering interest in the subject. In an introductory astronomy course where students learned how to operate telescopes and perform their own astrophotography, 71% of the students reported increased interest in astronomy and 89% of the students enjoyed the course due to its hands-on nature and practicality [35]. Research that explored *course-based undergraduate research experiences* (CURE) in astronomy found that students improved their sense of competence to perform astronomy research, developed a sense of belonging in the astronomical community, and saw themselves as both scientists and astronomers [40].

C. Sociocultural motivation for studying physics and astronomy

While STEM, physics, and astronomy identities potentially overlap, they also consist of some distinct constructs. Many individuals interact with physics in a formal educational setting or through external social influences. Astronomy may be more frequently introduced in informal educational settings or through popular culture. The different settings in which individuals interact with physics and astronomy allow for different experiences with the disciplines, which may alter the motivations for choosing them as majors and/or careers.

A sense of belonging, familial influence, community, and identity have been identified as key factors in fostering continued interest and success in college for physics majors. A sense of belonging facilitated by a supportive physics community may improve physics recruitment and retention [41]. Sense of belonging also relates to students' self-efficacy in physics [20]. Students' career paths are often influenced by their parents and teachers [24,42]. Although parents often rank the mathematics and science abilities of boys higher than girls [43], girls receive more encouragement to pursue physics than boys in high school [44]. Parents may encourage students to study physics by including them in their own physics hobbies [24]. Recognition from teachers also influences students' choices. Avraamidou [23] explored the influences upon three female high school students, noting that teachers directly recognized students' talents and encouraged them to pursue physics in college. Such recognition has been shown to contribute to the development of career aspirations in STEM fields [42].

Popular culture also has the potential to influence one's career choices, and there is a proliferation of astronomy-related media that are easily accessible for students of all ages. Students may first experience physics and/or astronomy from popular culture depicting astronomers, physicists, and scientific discoveries [42,45], which often facilitates interest to major in these fields.

III. CONCEPTUAL FRAMEWORK

There is a substantial gap in the literature regarding astronomy identity and why students choose to study astronomy. The present study utilizes Lent *et al.*'s social cognitive career theory [46] and STEM identity frameworks [1–4,14,18] to identify potential mechanisms for understanding how undergraduate students choose and persist in the study of astronomy. These conceptual approaches are grounded in social cognitive and environmental constructs that influence academic behaviors and career aspirations. In examining the astronomy-specific context through inductive analysis, a novel explanatory framework that draws upon social cognitive career theory and STEM identity frameworks will be developed.

Social cognitive career theory articulates factors that influence an individual's choice to pursue a particular field [46]. This theory draws upon Bandura's seminal work in social cognitive theory, which suggests that an individual's self-efficacy influences academic behavioral intentions, which are also guided by outcome expectations [47]. Lent *et al.* [48] suggested connections among self-efficacy, interest, and motivation, which contribute to persistence in a discipline. Intrinsic and external motivations serve as mechanisms for individual choices regarding academic pathways and desired careers [49]. Intrinsic motivation is one's tendency to seek challenges to improve learning and knowledge, and extrinsic motivation is when an individual's actions are facilitated by external pressures [50]. Sociocultural influences have reciprocal interactions with self-conceptions, motivations, and actions [51]. One example of these external motivations is the media [45]. Individuals may observe pictures of celestial bodies or hear about new astronomical discoveries. This exposure through social media, books, television, and films may inspire individuals to learn more about astronomy and develop lifelong interest.

Lent *et al.* [50] built upon Bandura's work by examining social cognitive influences on STEM-specific career choices. They identified prior academic competence as an influence on interest and vocational intention, along with outcome expectations, or the "belief that a given behavior will lead to a particular outcome" [[50], p. 424]. The present study explores astronomy students' self-efficacy, interest, and motivation for participating in astronomy through research and/or an academic major, while identifying both internal and external influences.

Several researchers cited recognition, interest, performance, and competence as contributing factors to STEM identity, a complex construct involving a student's self-identification with regard to the discipline [1–4,14,18]. Recognition is the acknowledgment of disciplinary competence by peers and/or STEM experts. Interest is one's desire to understand specific STEM concepts. Competence is the belief that one is able to understand a discipline, and performance is the ability to complete required STEM tasks [14]. Interest, competence, and performance may be considered intrinsic motivations, and recognition may be considered an external motivation [50].

Interest in a particular subject may come from self-efficacy, which is often rooted in academic performance and the belief that one can accomplish a task [46]. Self-efficacy and interest may be influenced by external factors such as recognition from peers and faculty [46]. A student who performs well might receive recognition, leading to validation that may influence choice of major. Students may start to see themselves as a physicist or astronomer [14]. Previously, competence was defined by academic performance [18], however, Gonsalves [52] modified this construct by distinguishing between performance and competence in a study exploring factors contributing to the recognition of doctoral (astro)physics students. Competence was redefined through specific skill sets, including problem solving, fine motor actions, and communication with physics vocabulary. However, recognition was often complicated by the traditional gender norms that are implicit to physics dialogues. Gonsalves suggested that students must often navigate stereotypes for their competence to lead to recognition [52].

Engagement in research early in one's undergraduate career may be instrumental in STEM career choice. At the undergraduate level, astronomy research usually consists of analyzing novel astronomical data; this work sometimes leads to publication, typically as coauthors with lead researchers and graduate students. Performing research allows students to help build an identity as a scientist [18]. Specifically, participating in research early in the academic pipeline allows students to bond with other members of the laboratory through shared experiences, which may contribute to a sense of belonging [17]. Through their research, students often become part of a community and receive recognition from others, which strengthens science identity [18]. Being part of a research group and experiencing recognition from faculty has helped undergraduate women to become socially integrated in their department [17].

There is a triadic reciprocity among self-efficacy, behavioral influences, and career expectations with regard to student participation in astronomy studies and research. Both self-efficacy and competence describe one's belief about how well they can perform specific tasks related to astronomy. Recognition relates to behavioral influences. The more positive validation a student receives, the more

socially engaged they may become in their department. Socialization between students and faculty has the potential to influence behavior and identity through recognition. Career expectations may be formed by performing research and interacting with faculty and graduate students. During this important and formative time, students may also learn skills necessary to be an astronomer, furthering their career expectations. These constructs informed interviews with students as a novel astronomy identity framework was inductively generated.

The present study identifies key factors that influence astronomy identity, examining students' choices through the lens of social cognitive career theory [46,48–50] and STEM identity frameworks [1–4,14,18] to propose a new astronomy identity framework for undergraduate students. An astronomy identity framework may shed light on how to increase the number of astronomy majors and improve the diversity and inclusion of the astronomy discipline. The present study aims to answer the following research questions:

1. What factors influenced undergraduate students' decision making in studying astronomy and/or participating in astronomy research?
2. What factors influenced persistence in astronomy research and/or the astronomy major?
3. How might an astronomy identity framework be differentiated from prior STEM identity frameworks?

IV. METHODS

A. Research design

A qualitative research design was employed with a transcendental phenomenological approach since it was necessary to understand multiple individuals' experiences in studying astronomy [53]. A *transcendental phenomenological* study focuses on interviewing up to 15 individuals with a shared experience and reduces data to specific quotes to provide descriptions and insights on their experiences [53]. Common themes may be identified and explored to understand how an event was experienced by the individuals. In this case, it was how and why undergraduate students chose to study astronomy, their experience in astronomy research and majors, and how these factors contributed to their astronomy identity.

B. Context and participants

Participants were recruited from two higher-education institutions in Southeast New York state. The first was a suburban research university with an enrollment of 26,000 students, and the second was an urban university with an enrollment of 23,000 students. These institutions were chosen to provide a purposefully diverse sample of study participants. Institution 1 offered both the astronomy major ($N = 54$ students in 2024) and minor ($N = 5$); 37% of the astronomy majors also majored in physics. Institution 2

only had a physics major, however, many faculty were active in astrophysics research. Institution 2 had 18 students who were physics majors performing research in astronomy. Participants in this study from institution 1 were astronomy majors, double majors in physics and astronomy, or astronomy minors. Those from institution 2 were physics majors performing research in astronomy.

In the United States, students are generally required to complete 120 credit hours of coursework. Approximately, half of these credits are general education courses and the other half are major specific courses consisting of mathematics, physics, and/or astronomy courses. Some institutions have an undergraduate research requirement for graduation, while other students may perform research independently.

Participants were recruited through e-mails to undergraduate astronomy majors and researchers, and they provided voluntary informed consent (IRB approval No. 2022-00287). All individuals who replied to the email were accepted into the study. The participants ($N = 10$) included six women and four men. Six participants were majoring or minoring in astronomy; four others majored in physics or Earth and space science and did research in astrophysics. Seven participants were juniors or seniors. Five participants self-identified as Hispanic, while the others were South Asian, Middle Eastern, and Caucasian. Notably, all participants identified as belonging to at least one demographic group underrepresented in astronomy. The characteristics of the study participants (identified by pseudonyms) are shown in Table I.

Participants were interviewed by one of the authors for 45–60 min between August 2023 and December 2023. Interviews were recorded and transcribed. The interview protocol (see the Appendix) was informed by the literature surrounding STEM identity and was worded specifically for astronomy. The transcriptions of the interviews were the main data source for the study and were used in the coding process.

C. Coding process

The coding process was conducted in three phases following procedures outlined by Creswell [53] and Saldaña [54]. *A priori* coding with elements of grounded theory were utilized [54]. First, open coding was used to identify key phrases in the transcripts that aligned with the research questions and conceptual framework. Open codes were then refined to have a better representation of the data. In the second phase, axial coding, the researchers utilized *versus coding* to identify nuanced information regarding positive, negative, and neutral influences on participants' interest in astronomy, choice to study astronomy, and astronomy identity [53,54]. Two of the general codes did not have axial codes. Four general codes contained axial codes relating to specific times, phenomena, or sense of identity. The axial codes for ten of the general codes

TABLE I. Characteristics of participants.

Participant	Institution	Academic year	Major	Astronomy research	Gender	Ethnicity
Student A	1	3	Physics; astronomy minor	No	Male	Hispanic
Student B	1	2	Astronomy	No	Male	Hispanic
Student C	2	4	Physics	Yes	Female	Hispanic
Student D	2	4	Physics	Yes	Male	Hispanic
Student E	2	4	Physics	Yes	Female	South Asian
Student F	1 and 2	3	Physics and astronomy	Yes	Male	Hispanic
Student G	1	3	Astronomy	No	Female	Caucasian
Student H	1	1	Earth and space science	No	Female	Caucasian
Student I	1	4	Astronomy	No	Female	Caucasian
Student J	1	2	Physics and astronomy	Yes	Female	Middle Eastern

contained versus coding, which was chosen to compare the influences of specific events on students' astronomy interest. Specific events were analyzed and identified as having a positive, negative, or neutral influence on a student's decision to study astronomy. In the third iteration, thematic coding took place. Thematic coding allowed for the organization of codes into groups to identify recurring patterns that formed an explanatory narrative building upon yet distinct from existing STEM identity frameworks [54].

A total of 38 open codes were identified. Codes are listed in Table II, along with their frequencies. Open codes were generally delineated into 15 axial codes, including categories such as early life inspirations, interest in astronomical phenomena, recognition from teachers and mentors, research experience, and identity constructs specific to astronomy. Notably, positive codes were more frequent for parents and family influence, socialization, performance, physics lecture and lab influence, and self-efficacy and confidence. However, negative codes were most common with respect to gender or ethnicity. The axial codes are discussed further in Sec. V.

D. Validity, reliability, and trustworthiness

Multiple measures were taken to ensure the validity, reliability, and trustworthiness of the qualitative methods. To improve the trustworthiness, the first author acknowledges that he was acquainted with three of the participants before they were recruited through formal interactions with astronomy research colleagues. The second author interviewed these participants to minimize potential bias and elicit more candid responses. Both authors strove to minimize potential biases through extended discussions in which alternative explanations were proposed, analyzed, and debated before reaching consensus.

A subset of three transcripts (30% of total) was first coded independently by the two researchers, who recoded the transcripts through six separate discussions with extensive deliberation to reach interrater reliability of 90% [55]. Interrater reliability was calculated by

$$\frac{N_{\text{agree}}}{N_{\text{total}}}, \quad (1)$$

where N_{agree} is the number of codes in agreement and N_{total} is the total number of codes in both agreement and disagreement between the two authors. Although percentage agreement does not account for random agreement [56], this method is sufficient when there are large amounts of codes and a lower likelihood of chance agreement.

Since a transcendental phenomenological approach was employed, the participants were recruited through criterion sampling [57]. Students were selected from a population of suburban or urban undergraduates who studied or performed research in astronomy, since it was presumed they had similar experiences with and knowledge of astronomy. The recruitment of participants from different universities was intentional to include students from diverse backgrounds [57].

During interviews, member checking allowed participants to add credibility by confirming their responses [58]. Member checking is when an interviewer rephrases responses to allow the interviewee to confirm the accuracy of the interviewer's interpretation [58]. The interviewers selectively repeated participants' responses so they would reiterate and confirm their meaning. Interviews were coded with an iterative process until data saturation, which occurred when no additional codes were identified [59]. The two researchers reached data saturation after coding the transcripts of seven participants.

An audit trail was established for this study, including documentation of the frequencies for each code (Table II). Positive influences were recorded 117 times, negative influences were recorded 30 times, and neutral influences were recorded 29 times from the interviews. The researchers used rich descriptions to provide deep, dense, and detailed accounts to boost credibility of the study [59].

V. FINDINGS

The findings are organized by the major themes identified during the coding process. First, external factors

TABLE II. Coding frequencies.

Code	A	B	C	D	E	F	G	H	I	J	Total
1. Early life inspirations (high school)	2		1		1			1			5
2. Early life inspirations (before high school)	2	2			1	2	2	2		1	12
3. Astronomical phenomena (directly observed)	1	1		1		2	1	1	1	2	10
4. Astronomical phenomena (pop culture)	1			1	1	2		2			7
5. Parents and family influence (positive)	1	2	2	1	1		1	2	1	1	12
6. Parents and family influence (negative)			1	1							2
7. Parents and family influence (neutral)			1								1
8. Mentor influence (positive)			2			4		2		2	10
9. Mentor influence (negative)											1
10. Recognition from teacher and mentor (positive)			1	1		1					3
11. Recognition from teacher and mentor (negative)			1	1							2
12. Astronomy community (positive)		1	2	2		5					10
13. Astronomy community (negative)			1								1
14. Research (positive)			5	3	1	7		2		1	19
15. Research (negative)				2						1	3
16. Research (neutral)	1			1			1	1			4
17. Socialization (positive)		1	2	3		5	1	5	3	5	25
18. Socialization (negative)		1						1	2		4
19. Socialization (neutral)		1				1					2
20. Gender or ethnicity (positive)			2	1							3
21. Gender or ethnicity (negative)			2	3	1		0	2		1	9
22. Gender or ethnicity (neutral)				1	1	2			2		6
23. Performance (positive)			1	2	1	1	3	1	2	2	13
24. Performance (negative)							6				6
25. Performance (neutral)							1			1	2
26. Physics lecture and lab influence (positive)	2		1	5	3	1			1	1	14
27. Physics lecture and lab influence (negative)			1						1		2
28. Physics lecture and lab influence (neutral)	2			1	3	1					7
29. Physics lecture and lab influence (introductory)	1		2	3	2	3					11
30. Physics lecture and lab influence (advanced)	2							2	1		5
31. Interest in astronomical phenomena			3	3	4	2	2	1	6	1	22
32. Self-efficacy and confidence (positive)			3	1		3	1				8
33. Self-efficacy and confidence (negative)				1			1			1	3
34. Astronomy identity (feels like astronomer)			2	2	2	2	1	1	1		11
35. Astronomy identity (does not feel like astronomer)				1			2			1	4
36. Astronomy identity (competence)			1	1	1	2			1		6
37. Astronomy identity (research)				1	1	2					4
38. Astronomy identity (community)			1	4	5						10

influenced interest in astronomy from family members, observing astronomical phenomena, and popular culture. Second, factors influencing persistence in astronomy included socialization, recognition, and relevant coursework. Third, factors related to developing astronomy identity included communities of practice, sense of belonging, and competence. Some of the findings focus on specific participants more than others, due to more insightful commentary that captured nuanced meanings. However, the findings are representative of all interviewed participants.

A. Factors influencing early astronomy interest

1. Observing the night sky and research

Students reflected on how they developed interest in astronomy early in their lives. Many discussed how their fascination with the sky facilitated their overall natural wonder and interest in science. Student F, a third-year physics and astronomy major who emigrated from Honduras as a child, described how he observed the sky without light pollution during blackouts when he was young:

Well, I always like to talk about one of my earliest memories when I was a little kid, back in my country, the city I lived in used to have regular citywide blackouts where there would be no electricity. And so, whenever that would happen at night, me and my family would kind of just hang out outside the front porch. And if it was a really clear night, then the sky would be filled with stars, because there would be no light pollution, since the whole city had no electricity. So, just that view of the stars, I guess, would be one of the first things that kind of got me interested.

For student F, the awe and wonder of the visibility of stars while in darkness was an experience he could share with his family that permeated his early memories. Student I, a fourth-year astronomy major, recalled similar experiences with her father early in her childhood, who would frequently use a telescope to teach his daughter about celestial bodies in the night sky:

I do like observing with my dad because he had a telescope. He got another one and a newer model at the time. He could, like, look at the moon and stuff like that. It was cool. That kind of benefited because you're like, "Oh"—I liked doing that. I guess to me, like, astronomy is ... almost like the final frontier in science and stuff like that because there's still so much to know and what research to be done.

Student B also noted he became interested in astronomy as a child, however, he did not understand how that might be manifested in his academic pursuits later in life. His early interest led to a high school research program where he experienced engagement, enjoyment, and the guidance of a mentor:

I've always loved astronomy. It was always interesting to me since I was a little child, and I would always say I wanted to be an astronomer, but I don't think I ever really knew what that meant ... So, in high school I wanted to actually try to do something in the field of astronomy, and I took part in a research program ... I was working alongside a mentor, and I was looking at astronomical data, and I really enjoyed it. It was a lot of fun for me. It felt good. It wasn't boring. I mean, looking into it it's like a lot of data sifting and it's very far removed from all the fun facts that I just used to read in astronomy books, but regardless I still had a deep passion for it, and I decided to keep pursuing it.

Student B enrolled in a research program where he was able to see what it was like to be a professional astronomer.

Performing data analysis and the everyday tasks of an astronomer strengthened his interest and facilitated his decision to pursue astronomy as a career.

All three participants were drawn to making astronomical observations at an early age in the company of their families and/or teachers. The sky presents a natural view of celestial phenomena that they found fascinating, inspiring, and relevant to their everyday lives. In terms of astronomy identity, lifelong, universal access to visible phenomena may allow students to feel a connection with the discipline before formal study.

2. Popular culture

Students also reported that popular culture influenced their interest in astronomy. Research has indicated that popular culture has the potential to act as a first learning experience for individuals, which may influence their choice to study astronomy [45]. Student D, a first-generation college student pursuing his second bachelor's degree in physics, was participating in research on exoplanets and cosmology. He recalled times in his childhood when he watched popular culture icons on television, which piqued his interest in astronomy:

Carl Sagan is probably my favorite human being to have ever existed. So, I grew up just seeing him sometimes on TV, which is weird because I'm not even that old, but I would still see some of the stuff. And I thought that his quotes and the way that he represented science was really interesting.

The way Carl Sagan spoke about science had a notable influence on student D; his observations of relatable popular culture icons inspired fascination and a desire to learn more about astronomy. Student F also mentioned Carl Sagan as an influence. In his case, Carl Sagan was a role model who influenced his career aspirations and desire to pursue this discipline. Even though he knew little about the field, the presence of such a compelling figure in popular culture fostered his early sense of astronomy identity:

Astronomy was always just something very interesting, and I want to say I think it was maybe early high school when I watched "Cosmos" by Carl Sagan, that's what made me realize, like, "Yeah, I want to be an astronomer." ... I didn't know exactly what that entailed back then, but I just knew that I wanted to do something with astronomy.

For both student D and student F, popular culture was a key early influence on their astronomy interest and career aspirations. Televised programs presented astronomy as a relevant, authentic scientific pursuit, while introducing role

models who sparked wonder in individuals by making astronomy simple and accessible.

B. Factors influencing choice and persistence in the astronomy major

1. Socialization

Students often mentioned how socialization with peers helped them persist through their astronomy studies. Several women astronomy students participated in a peer mentoring program for women in science and engineering. They meet weekly with a small group of 5–6 women in their major, along with a third- or fourth-year lead mentor, also in their major. Student J was a second-year physics and astronomy major performing research. When asked about how her peer mentoring group influenced her decision to study physics and astronomy, she commented on the shared struggles with balancing academics and life and performing well in coursework:

I cannot stress how much it helped me. Like, it was like a family ... And it really, like then slowly by slowly we got closer and closer with one another and it was great ... like, when you would struggle with the lab and to know, like, your friend—she struggles with—it really makes you see it's not just [me]—like one of the girls, she's in my modern [physics] class this year and we are so, so close. Like so close because of it, because of the mentoring. And, like, we have each other's back ... I think a lot more girls kind of try to have a dual life where they tried to live their life and then they also try to study in the physics major and the astronomy major. [...] And it felt so good like, it felt so good to, like, have time. Have time to do things except study ... and you have a friend to relate to.

The mentoring group allowed student J to meet other students in her major and become part of an astronomy community of like-minded women. Research has suggested that physics majors often require a supportive community [37]. In student J's case, she was able to share tensions, making her feel as though her struggles were typical and could be navigated with peer and mentor support.

Before his undergraduate career, student F had never formally used a telescope nor was he a part of an astronomy community. When asked about how the undergraduate astronomy club in his department influenced his decision to study astronomy, student F described how social relatedness contributed to his fascination with astronomy:

It made me feel more connected with other people that were interested in astronomy, within [the university]. And we didn't get to do much, but at least we got to, you know, set up some telescopes

and look out into a different planet, and I think that was my first time where I finally got to see Saturn with my own eyes for the first time. And we like to say, here in [university], that Saturn is the gateway drug to astronomy.

Participating in the astronomy club, a social group that met weekly to discuss astronomy topics and engage in public outreach, allowed student F to feel part of a community early in his undergraduate experience. He met people who shared his interest and enthusiasm for the discipline. Student F also noted observing Saturn contributed to his interest and persistence in astronomy. Both students J and F shared that socializing with their peers made them feel like they were part of a community of practice. Having these shared experiences within a major is an important factor for persistence [41].

2. Recognition from faculty and mentors

Participants noted receiving recognition from faculty and/or research mentors affected their choice to study and persist in their major. Student F was a junior in his astronomy major at the time of his interview. He transferred from institution 2 to start his junior year at institution 1. When asked about his confidence performing astronomy-related work, he responded, “You know, classes—it's a struggle. But when it comes to research, I feel a bit more confident.” Despite initially performing poorly in his coursework, participating in research and receiving positive feedback from mentors allowed student F to increase his confidence and persist through the astronomy major. He performed research with a mentor in galaxy structure and formation for the majority of his undergraduate studies, and he maintained a collaborative relationship with his research group from institution 2. His research group included faculty and students from multiple institutions, and he was selected for a leadership role in the group. When asked about his responsibilities as a mentor to younger students, he stated:

Yeah, I'm one of the mentors, basically ... They [faculty] always made it seem like the project that we're working on is my project, and so, any contributions, they acknowledge it ... So, I'm mostly doing the main bulk of the work.

Student F consistently received positive feedback from his mentor for the research he was conducting, which contributed to his sense of autonomy, agency, and competence. His contributions to the research project were acknowledged by his mentor, providing recognition for his own independent research and his mentoring of junior students. Independent research has been linked to building physics identity [17,60]. His leadership role as a mentor to more junior students in the research group and

recognition from his mentor facilitated his determination and perseverance.

Student C noted both positive and negative recognition influenced her choice to study astronomy. She started college as a physics major and was later accepted into a program that allowed her to perform astronomical research. When asked why she chose to study astronomy, she responded:

I'll be honest. I didn't really want to do astronomy. I wasn't really sure. I just knew I liked physics. I was good at physics in high school. I had a great physics teacher who got me really passionate about it and was super encouraging. And so, I was like "I want to do physics." [...] And it actually wasn't until I got accepted into [Program] that I knew I wanted to do research in astronomy. That same semester that I got accepted into [Program] I almost dropped out of my physics program completely because I had a professor say I wasn't fit for physics because I was a woman.

In high school, she received positive recognition from her teacher, influencing her to pursue physics in college. When student C started studying physics in college, she received negative recognition rooted in gender bias. The influence of faculty often influences the choice to persist in STEM [23,42], yet perceived bias may have the opposite effect.

3. Experiences in astronomy coursework

The quality of instruction in formal classroom settings contributed to students' enthusiasm for astronomy. Student I was a senior astronomy major who was involved in a peer mentoring group for women in physics and astronomy. Although student I did not participate in research at the time of the interview, she indicated she would start research in the subsequent semester. She was asked about how her astronomy courses influenced her decision to major in astronomy.

Honestly, the most influential right now is the class that I'm currently taking. Because I do think it is the best, like, professor I've had in a long time. But the other ones—[Astronomy Course] I think it was—was very nice. I like that course a lot, which did help.

For her, the professor's open demeanor and pedagogical approach made the course enjoyable, which improved her interest and engagement with the discipline itself. Conversely, some students who did not enroll in a significant amount of astronomy coursework expressed less of an astronomy identity. For example, student E was a fourth-year physics student who researched brown dwarfs. She

enrolled in mostly physics coursework as opposed to formal astronomy courses. She applied to her institution because she was interested in an honors program, although they did not have an astronomy major. Student E was asked whether she felt capable of doing astronomy-related tasks. She responded, "Let's say 6 out of 10," and further elaborated on how she thought she could improve her knowledge:

If I were to take more courses on maybe physics, and math, and astro in general. Because I haven't taken the Astro 101 course. I've only ever taken Cosmology, which was a special topics course and then a seminar course ... I don't know much of the basics with orbits and what-not in Astro 101 or whatever.

For student E, the lack of relevant coursework affected her confidence in performing astronomy-related tasks. Coursework can have both positive and negative effects on persistence. Skilled instruction has the potential to inspire students to choose to study physics and/or astronomy, especially in introductory courses [33]. This was especially true for student D, who was interested in astronomy since his childhood but did not know how he could become an astronomer. His introductory astronomy course was instrumental in his choice to pursue astronomy study through research, even though he perceived that one had to be brilliant to do so:

I've always loved space and star stuff and I—one, I had never thought that could be an actual career that people could do ... when I found out it was a career, which was at [school], because I took an astronomy class there. I thought you just had to be kind of born a genius.

Working with faculty through coursework can have a significant impact on a student's choice to study astronomy—this often occurs through recognition and improved confidence. Research has indicated there is a common perception that mathematically intensive fields require superior cognitive skills [37]. Introductory astronomy requires basic algebra and sometimes calculus [61], and may give the impression one must excel at advanced mathematics in order to become an astronomer [62]. Such impressions may impede students from underrepresented groups from studying astronomy [62]. Many participants noted the importance of introductory astronomy coursework in deciding to study astronomy and persisting in the field.

C. Factors influencing astronomy identity

1. Communities of practice and career expectations

Students who participated in research in an active, welcoming community noted it positively affected their

sense of astronomy identity. When student D first started astronomy research, he was excited about doing work on exoplanets, although he did not feel that he belonged in the field. He noted he experienced a degree of imposter syndrome, a phenomenon when individuals feel they do not belong in a group or discipline [12,63]. He started to develop a sense of astronomy identity by performing research. When student D was asked if he saw himself as an astronomer and the process behind developing his sense of identity, he responded:

Not only do I see myself as an astronomer, I think it's kind of become a big part of my personal identity ... I guess for the first couple of months, having worked with [mentor], I just—I thought it was way too incredible to be working on something as exciting as pointing a telescope at the sky and collecting data on stars. So, I definitely felt what I think most people feel, which is a lot of imposter syndrome ... I felt like any moment the other shoe's going to drop and people are going to be like, "No, you don't belong here." I feel very welcomed in the community. And I feel like that is what has allowed me to see myself as more of an astronomer. So, yeah, it's really—amongst my family, amongst my non-STEM friends, I am the astro guy. And I love it.

Student D had two separate research mentors who contributed to his sense of belonging in a community of practice. This aligned with Ivie *et al.* [12], who reported students were 1.77 times more likely to persist in astronomy if they had a secondary mentor. In addition, members of his team viewed him as an important part of their group, strengthening his astronomy identity.

Student C was a fourth-year physics major researching galaxy evolution. She was a first-generation college student born and raised in New York city. Half of her family immigrated from Puerto Rico. At the beginning of her undergraduate career, her family questioned her choice to pursue astronomy. Without support from her family, student C was at a crossroads between astronomy and physics. When she was asked about what made her choose astronomy, she answered:

I'll be honest. I didn't really want to do astronomy. I wasn't really sure. I just knew I liked physics ... But I wasn't sure if I wanted to do the very, very small or the very, very big. So, it was either quantum or astro because I thought those were really, really cool subjects. And it actually wasn't until I got accepted into [school] that I knew I wanted to do research in astronomy ... The community of [school] astro students

really made me feel at home because I didn't know anybody who wanted to do physics other than me before I got into [school].

Belonging to a community of practice attracted student C to astronomy. She met others with similar interests through her astronomy research, and they made her feel supported. Being involved in a peer community of practice helped develop her sense of identity as an astronomy researcher. Student F also participated in a community of practice. In his case, he was exposed to research and he started to see what it was like to be a professional astronomer. When student F was asked whether performing research affected his desire to pursue astronomy, he responded:

In a way, yeah, because I finally realized what is it that it takes to be an astronomer, which I didn't know back then, but I do now, that it just involves a lot of coding, a lot of computer stuff. So, yeah, it gave me a more clear view of how it is to be an astronomer ... and just seeing how everything works. It definitely gave me kind of like an ease of mind, because I kind of knew what I would be—it made me see, like, what I would be doing if I were to stay in astronomy.

Performing research gave student F a realistic look at the day-to-day workings of a professional astronomer. These career expectations influenced his academic journey and solidified his vocational aspiration. Student F chose to continue studying to become an astronomer even though he was struggling with his courses. This resilience was influenced by gaining insight into being a professional astronomer through research, which positively affected his sense of competence. Student F's actions are consistent with Bandura's research [47] suggesting academic behavior may be influenced by competence and career expectations.

These three participants (students C, D, and F) engaged in research within a community of practice. The participants discussed how their research experiences contributed to their sense of identity through collaboration and establishing career expectations. Members of their community saw them as astronomers, building astronomy identity through this recognition and mutual respect.

2. Sense of belonging

Participants often noted that a sense of belonging contributed to their emerging astronomy identity. Student D spent a significant amount of time searching for an academic place where he belonged. He was welcomed enthusiastically in his first research group and then again in his second research group. When asked about his sense

of belonging in the astronomy and physics community, he responded:

Yeah, I mean, I wrote about this in my grad school application, which I'm doing now, but I actually have never in my entire life felt like I fit in the way that I do now when I originally switched to physics. It's like my people.

Student D was invested in a community in which he was surrounded by others who had similar interests. Members of his community were able to discuss future steps for astronomy academic pathways, giving student D the motivation to continue astronomical research while understanding career expectations. Student J also shared her feelings of belonging in the physics and astronomy major focusing on undergraduate and graduate student communities.

I think it's more so with the grad students that I feel more connected with. Because they, like, kind of went through everything ... But I think the community is always, like, always trying to be fun. Like have fun but also learn and try your best. It's always motivation to push, push, push harder and be better and always—and I see that in [Astronomy Club]. Every day you see kids studying and it makes you study.

Student J felt a stronger a sense of belonging in her department because she viewed the graduate students as role models, individuals from whom she could seek assistance and advice. When discussing “kids,” student J was referring to how her undergraduate peers built an environment where students could support each other informally, experience mutually beneficial astronomy problem solving, and maintain accountability. Student G also discussed a sense of belonging, however, it was with a mentoring program within the department.

Because I think in terms of, like, [mentoring program] it is more common to talk about, like, what you're struggling with or like, you know—that sense of belonging as well. Because I feel like as a woman it's easier to talk about it to each other, that you don't feel you belong as easily. And that gives you a sense of belonging in a way because you're like, “You're not alone.” [...] There's like a good mix of people that—some are really confident in what they do and some, they're just kind of like ... they're just regular students. So, I feel like it's not as easy to find other people who are as open about stuff like that. [...] I don't find it as much in the actual, like, department or club as much as I do in the [mentoring program].

Student G noted being part of a community program for women in STEM, where students were open about their struggles studying physics and astronomy. This made her feel like she belonged because of shared experiences.

A sense of belonging can be developed through communal activities and having role models. Students D, J, and G were involved with communities where they had peers and senior students whom they could ask for help. As their skills developed, they themselves were able to help more junior students. Being a part of an active community often allows students to develop positional status as having a high level of competence. This recognition directly contributes to one's sense of belonging [20].

3. Competence

Multiple participants indicated confidence in their abilities affected their sense of astronomy identity. Student C built competence through hands-on research experience. While she was confident in her abilities to perform astronomy-related tasks, she did not always feel this way when faced with the failures that often occurred in research. Student C described the process of how she developed a higher level of competence through research in the face of both gender and ethnic biases:

Failing. Figuring out why I failed and learning from it. I didn't know how to program. Learning how to program has made me way more confident in my research abilities. And just the practice of being in these academic spaces has made me more confident where it's less intimidating to be in a room full of White guys. And yeah, I think all those things, that it's—the skills and the practical uses and the practice and the time and effort I put, but also just the exposure to what academia is like so that it's less intimidating.

Practicing astronomy-related skills such as programming and learning from her mistakes helped student C become more comfortable in academic spaces where latent gender and ethnic biases existed. Student D mirrored similar experiences regarding his ethnicity, stating “It felt like in a way I was representing—I'm not saying that I was, but in my head sometimes it felt like, ‘Oh, I'm representing this larger [Hispanic] group’”. He has also mentioned his confidence in his abilities grew over time:

I compare myself to myself five years ago when I never thought I could do what I'm doing now. And I also try to just keep in the back of my head recent accomplishments that I've had that kind of keep me peppy and kind of, yeah, feeling confident enough to be able to continue going.

Student D was able to build confidence in his abilities through research, performing astronomy-related tasks, and iterative failures that became successes. Confidence allowed him to overcome his imposter syndrome and persist in astronomy. Student E echoed similar feelings regarding competence. While she previously stated that not taking any astronomy specific courses had negatively affected her sense of identity, performing research did have a positive effect on her competence and identity, commenting, “Yes, I feel a little bit more capable than freshman year when I didn’t know any coding and how to think like a scientist.” Student E was able to build a sense of competence from performing research and building her capacity to complete astronomy-related tasks.

Student H, a first-year Earth and space science major, had not yet participated in astronomy research at the time of the interview. When asked about her sense of astronomy identity, she responded:

Yes. For sure. I have a telescope and I’m always looking at the stars and trying to find new ways to see, like, how I can track when certain nebulae are up and how to stack images and stuff, so it looks very clear. But I’m always, like, trying to learn new things about astronomy.

Student H built her sense of identity and agency through capturing images of celestial bodies and adding knowledge and skills to her repertoire. This competence contributed to her sense of identity because she was using some techniques observational astronomers use.

Three of these students (C, D, and E) performed research during most of their undergraduate years. Student H used her own telescope to perform astrophotography. They developed their skills through hands-on experiences, increasing confidence and astronomy self-concept. This indicates a relationship between competence and astronomy identity.

VI. DISCUSSION

The qualitative data analysis in this transcendental phenomenological study contributes to an undergraduate astronomy identity framework for those who major in and do research in the discipline. Previous studies on astronomy identity formation examined how participation in course-based research affects astronomy self-concept [40], and how students in grades 5 through 9 develop astronomy identity [30]; however, an astronomy identity framework for undergraduates has not yet been established. This work addresses a gap in astronomy education research. The work is also distinguished by the large number of women and Hispanic participants who are traditionally underrepresented in astronomy, some of whom reported experiencing bias yet they persisted in the field.

The present study builds upon prior STEM identity research [1–4,14–18,26,28,31,60]. Related studies found that performing undergraduate research and participating in a community of practice facilitates a sense of identity [14,18,60]. This astronomy identity research is differentiated from prior identity frameworks by identifying 6 factors within two interpretive lenses. The *internal factors* are (1) interest, typically rooted in observing naturally occurring astronomical phenomena and popular culture, (2) competence, and (3) sense of belonging; while the *external factors* are (4) socialization, (5) recognition from peers, experts, and families, and (6) astronomy career expectations. These thematic elements are described in detail.

A. Early interest in astronomy

The first research question examined factors that influence undergraduate students’ decision making in studying astronomy and/or participating in astronomy research. Students often developed *interest* in astronomy at an early age through observing the night sky directly. This is often associated with positive shared experiences with their families, which suggests a cultural synergy with the scientific world. This may trigger emotional connection with astronomy sparking an interest at an early age [32,60], which is an intrinsic motivation for continuing with formal astronomy study [49]. Some students were also influenced to study astronomy through popular culture, which may act as a first astronomy learning experience for students [41,45]. Astronomy may be addressed in popular culture and later discussed in social situations or in the classroom acting as extrinsic motivator, influencing an individual to study and/or participate in astronomy study and research. Most participants in the present study mentioned popular culture and early memories of astronomy, which may be a differentiating feature of astronomy identity from other forms of STEM identity in general.

B. Persistence in the astronomy major

The second research question explored factors influencing persistence in astronomy research and/or the astronomy major. Students shared that *socialization* within the major and working with faculty were common sources of encouragement for students to persist in astronomy. Socialization through peer mentoring groups may create positive external influences on students’ behavioral choices [46,49,64,65]. Socialization included but was not limited to laboratory partnerships, peer mentoring groups, and astronomy clubs. Students developed bonds and shared the stresses of their major and research tasks. During these times, students often discussed what courses to take, research opportunities, and other job or internship opportunities without faculty present. The implicit support and camaraderie often influenced the decision making of students to pursue astronomy as a major or research focus. Students sometimes joined a

particular research group because of peer influence. These social experiences have been shown to be influential in shaping students' astronomy identities and sense of belonging [17,20].

Working with faculty was also influential in astronomy identity formation and persistence in the field. *Recognition* from faculty and mentors was an extrinsic motivation that directly affected students' behavior and one's competence, consistent with prior research [14,46,49]. Positive recognition contributed to competence; this confidence in astronomy tasks facilitates a *sense of belonging* in the field [14,17]. This external validation may help students feel part of the greater astronomy community. Recognition has also been shown to help build STEM identity, specifically for women [14]. While recognition is more influential for women [14,45], men in this study more often mentioned receiving positive recognition, indicating potential gender biases may still exist. Students also shared that peers and family members recognizing them as astronomy experts contributed to their social and academic identities.

Finally, many students commented that relevant coursework affected their persistence in the major. Coursework often lays the foundation for astronomy, and it may positively or negatively affect students' persistence. Coursework may act as an intrinsic influence since students aim to challenge themselves in their coursework to improve their own *competence* and desire to learn about astronomy [49]. Alternatively, coursework may act as an extrinsic influence. Students may socialize with and receive recognition from faculty and other students through asking and answering questions, participating in class discussions, and helping their peers. Recognition from faculty may be an extrinsic influence, affecting students' interest and *career expectations*, contributing to astronomy persistence [15,25,49].

C. Differentiating between an astronomy and STEM identity frameworks

The third research question addressed the operationalization of an astronomy identity framework that builds upon and is differentiated from prior STEM identity frameworks. STEM identity frameworks have often included recognition, interest, competence, and performance [1–4,14,18].

The proposed astronomy identity framework consists of a dynamic interplay among interest, recognition, socialization, competence, sense of belonging, and astronomy career expectations (Fig. 1). The six constructs can be categorized into internal and external influences affecting astronomy identity development. Internal influences include interest, sense of belonging, and competence (represented in orange); while external influences include recognition, socialization, and astronomy career expectations (represented in blue).

Interest belongs in both general STEM and astronomy identity frameworks; however, the source of interest in the



FIG. 1. Emergent astronomy identity framework.

frameworks may be different. In the astronomy identity framework, interest often stems from early observations of the night sky and popular culture. Colantonio *et al.* [30] showed there was a direct link between interest and astronomy identity in children, and the elementary and middle school years may be a pivotal time frame for this to occur. Popular representations and contextualization of astronomy in films, television, social media, and books often contribute to student interest in the field. This is consistent with research that suggesting children's interest in STEM is facilitated by family science conversations and resources that provide access to science-related activities [1]. In astronomy, these conversations often occurred in the early years during observations of the sky. However, this contrasts with research that found that observing stars in elementary and middle school years no longer contributed to STEM identity in college years [2]. Consequently, the proposed astronomy identity framework aligns interest development rooted in early observational experiences and popular culture, which differs from some previous STEM identity frameworks.

Recognition originates from prior work in STEM identity [18], defined as receiving validation by others as a science person. Recognition in the astronomy identity framework is being formally or informally identified by others as an astronomer [18]. This may come from faculty and mentors publicly supporting an individual as a skilled astronomy student and researcher [14]. Recognition from faculty provides validation and ability confirmation [17], contributing to one's sense of agency, confidence, and identity. Faculty may recognize the student's competence and give them specific tasks that would be performed by a professional astronomer, which may build accurate career expectations.

Informal sources of recognition come from individuals outside the field—for example, family, friends, or the general public [18]. Rethman *et al.* [66] noted students who participated in public outreach events developed a

sense of physics identity through recognition because the general public viewed them as physicists—this may translate to astronomy. Several participants in the present study started to develop a sense of astronomy identity because their family and friends saw them as astronomers.

The astronomy identity framework adopts the definition of competence as one's belief in their ability to perform astronomy-related tasks and acquire relevant skills, which is similar to other STEM frameworks [14,52]. However, the source of competence in astronomy may be more likely to originate from research experiences since astronomy major programs are far less common. Developing a sense of competence is related to receiving recognition from mentors and peers [46]. For many astronomy students, this may only be possible in an undergraduate research program.

Sense of belonging is feeling that an individual is a part of the astronomy community, which is often facilitated by participation in research [17,18,40]. Astronomy undergraduate researchers typically socialize with other students, faculty, and research staff. Such interactions may make one feel part of a community and socially integrate them in their departments [17]. If a student believes they can do what is required of an astronomer, they may feel as though they belong in the department, often from faculty recognition and mentoring other students. A sense of belonging is also built through socializing with peers in their community, allowing students to discuss classes, research problems, and navigating tensions.

Socialization is a construct in the astronomy identity framework and is intertwined with a sense of belonging. Socialization with peers and faculty occurs in formal and informal settings such as performing research [17], participating in astronomy clubs [34], joining peer mentoring groups, or participating in other relevant communities of practice. Eight of the ten participants cited socialization as an important influence in studying astronomy. Socializing acts as an external behavioral influence as students may make decisions based on what faculty and peers do or say [46,49]. Socializing with faculty may give students a clear representation of the day-to-day life of a professional astronomer. Socialization is also tied to receiving recognition. In communities of practice, students may help one another. Through these reciprocal processes, students may view themselves as astronomers in practice.

The last construct related to building astronomy identity is career expectations, which are informed by the notion that a particular behavior will lead to a desired outcome [46]. Career expectations are how students perceive particular vocations in terms of day-to-day tasks, personal values, and potential for advancement. Students' career expectations can be developed by performing astronomy research and socializing with faculty. The behaviors of faculty and peers have the potential to act as an external influence [46,49]. Performing research sets the expectations of an astronomy career by developing skills,

normative assessments of competence, and awareness of job opportunities. It has been shown performing research positively affects students' astronomy identity and helps develop the skills required to be an astronomer [40]. As students hone their skills through research, they become more competent and may see themselves as astronomers.

D. Astronomy identity and traditionally underrepresented students

The astronomy identity framework presented in this paper was derived from the experiences of individuals who identify with traditionally underrepresented ethnic and gender groups in the astronomy field. This was not a directly planned sampling strategy, rather, all of the students who volunteered were included in the present study. The voices of these students are particularly insightful given their lack of identity representation among astronomy majors [6,7] as well as higher education faculty [67]. The astronomy identity constructs may suggest ways in which traditionally underrepresented students may be engaged and inspired, which would serve to diversify the future astronomy workforce. For example, informal learning opportunities for urban children may improve interest and facilitate an early sense of belonging [68,69]. Recognition and socialization may counter the sense of isolation that may inhibit persistence in STEM majors, which is chronically problematic for students underrepresented in these fields [70,71]. The astronomy identity framework may inform departments how to be more inclusive and help foster safe spaces for research participation, socialization with peers and faculty, and communicating expectancy for astronomy-related future careers. This is particularly important since several students reported experiencing direct and indirect bias in their undergraduate settings.

E. Implications

There are several implications from the qualitative analysis presented in this research. Informal outreach programs should be expanded and encouraged to inspire the next generation of astronomers. This may be through university partnerships or informal science institutions. Informal science institutions have been effective in providing interactive exhibits for students to learn science that is difficult to access in traditional classrooms [68,69]. Professional learning programs for precollege science educators may encourage them to incorporate astronomy education resources in their science instruction [69].

Introductory astronomy courses are important for recruiting students in physics and astronomy departments [38,39]. Astronomy programs may make research a required component of the major, leveraging the positive outcomes identified by prior studies [17,60]. By performing research, students often receive recognition from peers and faculty, increase their competence, and develop a sense of

belonging through socialization. This experience often results in a positive impact on students' astronomy identity, which may inspire them to persist in the major. Socializing with astronomy faculty is important and should be done more frequently to give students a better idea of what they can expect for a career in astronomy, which may set realistic and obtainable goals for students' futures.

F. Limitations

This study has several limitations. First, there was a relatively low number of participants as there were not many astronomy majors and students performing astronomy research. Not every participant was an astronomy major, and each participant interacted with the field of astronomy in different ways. Second, participants for this study were selected from higher education institutions in New York state—it is possible that some of the research may not translate to other geographic regions. Third, interview transcripts were the only source of data. Including other sources such as observations and course artifacts has the potential to increase the validity and reliability of the analysis. The retrospective interviews discussed events from the participants' past that could not be directly observed. Fourth, the researchers are physics education and astronomy educators at higher education institutions. The coding of interview transcripts may have been affected by the researchers' biases.

G. Future work

Future work in astronomy identity research might consider more in-depth studies of identity development at various points in the STEM pipeline. Large-scale quantitative studies would provide samples for inferential analyses of relevant predictors of astronomy identity formation. Other studies might utilize qualitative approaches, since much research in informal contexts involves smaller samples. For example, astronomy interest may be facilitated at early ages through public outreach programs since most students are not exposed to formal astronomy instruction in precollege settings [23,28]. Informal public outreach events have the potential to spark interest and create an emotional response with parents to influence students to study astronomy in college. Future work might explore how students' participation in astronomy outreach affects their identity formation in each of the six constructs identified in the present study. Research might involve family members and teachers in retrospective studies that assume a broader sociocultural approach to longitudinal identity formation.

H. Conclusions

Research on astronomy identity is limited, and the research presented in this work proposes an astronomy identity framework by examining mechanisms related to

interest and persistence in astronomy. The development of an identity framework may provide insights on fostering interest and persistence in astronomy. Interest in astronomy forms at an early age, often from observing the night sky or through popular culture. Persistence in an astronomy major is often influenced by working with faculty and socialization within the major. Astronomy identity consists of interest, recognition, competence, socialization, sense of belonging, and career expectations. Astronomy education researchers might utilize this work to expand and diversify participation in the field.

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APPENDIX: INTERVIEW PROTOCOL

1. Demographics
 - What college(s) have you attended?
 - Why did you choose your college(s)?
 - What is your class standing in college?
 - Where are you from?
2. Why did you choose to study/perform research in astronomy?
 - What were early influences in life to interest you in astronomy/science?
 - Do your parents have who work in a STEM field?
 - Did your parents encourage you to pursue STEM?
 - With whom do you perform research?
 - Did your research mentor influence your decision to study astronomy?
 - What high school did you go to? Did you go to a community college?
 - When did you declare astronomy major or decide to join a research group in astronomy?
 - What area do you do research in?
 - Do you enjoy it? Why?
 - What topic(s) do you like most in astronomy? Why do you like that topic?/What do you find interesting about the topic?
 - How do you think your gender/ethnicity experiences or intersectional identities may have influenced your decision to study astronomy?
 - Do you feel confident in your ability to do work related to astronomy?
 - Does doing research change your opinion about astronomy/physics?
 - Describe your interactions with your peers and mentors.
 - How do your interactions with peers and mentors affect your sense of identity as an astronomer?
 - How have your past experiences in science influenced your interest in astronomy.

- Do you see yourself as an astronomer or “astronomy person”?
 - Do feel a sense of community/belonging in the astronomy community/department? How does this affect your identification with being an astronomer?
3. Do you think the physics and/or astronomy labs helped with your understanding of the scientific method?
 - Did the physics/astronomy labs improve the way you think critically and improve your scientific literacy?
 - Did the physics/astronomy labs help with your understanding of astronomy concepts?
 - Did the physics/astronomy labs help with your understanding of physics concepts?
 4. Do you enjoy astronomy more or less than before you enrolled in the introductory physics lab?
 - Why? What may have changed your mind?
 5. To what extent did you interact with your instructors or other students in your physics/astronomy labs?
 - Did you go to office hours?
 - To what extent did you socialize with your peers?
 - Whom did you contact if you didn’t understand how to complete the lab?
 - Do you think you would’ve benefited from formal discussion groups? (if taking online labs).
 6. What are your plans after graduating?

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