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Tracking the Evolution of Interdisciplinary Identity-Based Motivation in Engineering Graduate Students: A Longitudinal Study

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Tracking the Evolution of Interdisciplinary Development in STEM Graduate Students: A Longitudinal Study

Abstract

The strongly "paradigmatic" or "high-consensus" nature of STEM fields—characterized by well-established theories, high agreement among practitioners about accepted topics and methods, clear disciplinary boundaries, and standardized practices [1–4], [5] — can create cognitive and cultural barriers to interdisciplinary STEM graduate student identity development and motivation [6,7].

To explore these barriers, this paper presents a longitudinal study, a secondary analysis of an existing data set, to explore how STEM graduate students' interdisciplinary development evolves over enrollment in an Interdisciplinary Disaster Resilience (IDR) program. Utilizing Oyserman and James's [8,9] Future Possible Selves (FPS) framework, we analyze multiple annual interviews for each student, focusing on three key aspects of FPS [10]: self-perception as an interdisciplinary scholar, desire to be an interdisciplinary scholar, and perceived possibility of becoming an interdisciplinary scholar. We employ pattern coding [11] and thematic trajectory analysis [12] to visualize and interpret the dynamic changes in these motivational components over time.

Our preliminary findings illuminate three distinct developmental trajectories, illustrated by three individual cases: 1) the "growth alignment pattern," where students show synchronized progress across all dimensions of interdisciplinary development; 2) the "transformation alignment pattern," where students move from complete resistance to acceptance across all three dimensions with at least one dimension shows a sharp change, and 3) the "mixed progress pattern," where students experience fluctuating self-perceptions while maintaining stable desire and possibility assessments. Findings demonstrate how students negotiate between their STEM professional identity and emerging interdisciplinary identity, providing insights into the challenges and opportunities of interdisciplinary graduate education. This study contributes to understanding interdisciplinary identity development in STEM education and offers methodological insights for analyzing qualitative longitudinal data. The results have implications for interdisciplinary program design and suggest potential intervention points to support students' development.

Introduction

The imperative for interdisciplinary approaches to complex challenges has gained increasing prominence in recent decades [13–15]. However, STEM graduate students face distinct barriers developing interdisciplinary scholar identities due to their fields' high-consensus nature [3,16–20], characterized by established theoretical foundations, standardized methods, and delineated disciplinary boundaries [5,21–23]. These epistemological conflicts are further complicated by rigid departmental structures and competing expectations between disciplinary and interdisciplinary programs [6,24–26], as Holley [27,28] demonstrates through longitudinal research. Theirs and other recent studies indicate that STEM graduate students often struggle with imposter syndrome, threatened sense of belonging, and diminished motivation when attempting to pursue interdisciplinary work within traditionally structured STEM departments [29–32].

While existing research has illuminated various factors influencing interdisciplinary development, our understanding of how STEM graduate students' motivation and identity as

interdisciplinary scholars—involving ongoing negotiation between disciplinary training and interdisciplinary aspiration—evolves over time is more limited [28,31,33]. The dynamic nature of this development process requires longitudinal investigation [1,32,34].

Theoretical Framework
This study employs Future Possible Selves (FPS) theory [8–10] to examine students' longitudinal development. FPS posits that people's motivations are shaped by their visions of potential future selves, who they might or want to become. The theory emphasizes three factors influencing motivation: connectedness (how strongly individuals link current actions to future identities), congruence (alignment between current and desired identities), and perception of difficulty (assessment of barriers to achieving desired identities). The framework's emphasis on temporal development and multiple structured dimensions of development makes it particularly suitable for this secondary longitudinal analysis of interdisciplinary identity formation in STEM contexts.

   We applied this framework to an existing data set consisting of annual interviews with STEM graduate students enrolled in an interdisciplinary program. As explained in Methods, because the original interview protocol was not designed using the FPS framework, we operationalized these influence factors based on the available data, resulting in three dimensions [35]. First, self-perceived progress toward becoming an interdisciplinary scholar (mapping to FPS connectedness), captures how students view their development on a continuum from not perceiving progress to fully identifying as interdisciplinary. Second, desire (mapping to FPS congruence), reflects students' motivation to develop an interdisciplinary identity. Third, perceived possibility of attaining interdisciplinary scholar status (mapping to FPS perception of difficulty), captures how students assess their ability to achieve this identity within their academic context.

Purpose Statement and Research Question
The challenges inherent in fostering interdisciplinary scholarly development among STEM graduate students necessitate a deeper understanding of how their motivations and identities evolve. This study begins to address this through longitudinal analysis of graduate students' developmental trajectories to answer the question: ***How do* STEM *graduate students' (a) self-perceived progress toward becoming interdisciplinary scholars, (b) desire to be them, and (c) perceptions of their possibilities for becoming interdisciplinary scholars evolve during their enrollment in an interdisciplinary certificate program?***

Methods
Study Site and Project Background
This study examines students enrolled in an Interdisciplinary Disaster Resilience (IDR) graduate certificate program, formerly funded by an NSF Research Traineeship (NRT) grant at a large public research university in the United States. The IDR program provided supplemental interdisciplinary training to graduate students while they maintained primary affiliations in their disciplinary departments. The program requires 12 credit hours of coursework, including core courses in interdisciplinary methods and resilience theory, plus interdisciplinary electives. Students also complete a research thesis or dissertation with an interdisciplinary committee. The program explicitly aims to develop students' capacity to integrate methods and perspectives across disciplines while maintaining deep disciplinary expertise, creating a rich context for examining how students navigate between disciplinary and interdisciplinary identities.

Participants and Defining Interdisciplinary Graduate Students
In this study, interdisciplinary graduate students are defined as graduate students formally enrolled in disciplinary STEM departments while simultaneously pursuing a graduate certificate in the Interdisciplinary Disaster Resilience (IDR) program. These students' dual enrollment created natural tensions between (inter)disciplinary identities, making their experiences particularly relevant for understanding interdisciplinary development in high-consensus fields.

The larger study this paper stems from is a longitudinal case study of 11 STEM graduate students enrolled in both their disciplinary departments and the IDR program between 2019 and 2023, with a total of 30 interviews. In this paper, we present preliminary findings through detailed analysis of 3 cases with 11 interviews coming from the larger dataset, where each selected students' interviews represented distinct developmental trajectories identified through analysis of the full dataset. These three cases were selected through purposeful sampling [36] based on: (1) their clear representation of distinct developmental patterns that emerged from analysis of all 11 students, (2) richness of their longitudinal data, and (3) clear articulation of identity negotiations between disciplinary and interdisciplinary orientations.

Data Collection
This study's secondary dataset consists of 11 one-hour semi-structured interviews from 3 students (one with 5 interviews and two with 3 interviews each) originally collected as part of general studies on interdisciplinary graduate student identity development. All interviews were conducted by the program's graduate research assistants (one of whom is one of the authors of this paper), who are all educational researchers who had observed and taken courses in the program and had built significant rapport with the participants over time prior to data collection.

The interview protocol focused on understanding students' perceptions of themselves as interdisciplinary scholars through questions targeting: their perceptions of (inter)disciplinary expertise, their definitions of "interdisciplinary," their desire to be interdisciplinary, and their self-perceived progress toward becoming interdisciplinary scholars. As mentioned in the theory section, this study's coding framework stemmed from the interview protocol's questions, which aligned with FPS's emphasis on self-perception, desire, and perceived possibility.

Data Analysis
The overall analysis process involved two main phases. First, we analyzed all 30 interviews from the 11 students in our broader dataset to develop our coding framework and identify distinct developmental trajectories. This broader analysis allowed us to understand the range of experiences and patterns across the full dataset. Second, we conducted a detailed case analysis of the three students with eleven interviews whose experiences particularly exemplified distinct developmental patterns identified in the full dataset analysis. These cases provide rich illustrations of how different students navigate the complex journey of interdisciplinary identity development over time.

Secondary Data Analysis
Because data collection in this study was not guided by the research questions, our work here can be characterized as secondary data analysis [36–38] and thus warrants additional quality considerations. To that end, we turn to the SHARE framework [36]. While a full review of how we applied the framework to this study is beyond the scope of this paper, full details are available in a forthcoming dissertation [39]. Most importantly, both authors of this paper were involved in the design of the original interview protocol, and the lead author conducted many of

the interviews. In addition, though not developed using FPS, the interview questions do address students' self-perceptions of themselves as interdisciplinary scholars, their desire to be interdisciplinary, and their perceptions of how possible that outcome is in light of the opportunities and barriers in their experiences, and our initial analyses indicated that the data were sufficient to support the use of FPS in analysis [35].

Initial Coding and Codebook Development
Once the team determined that the existing data was suitable for secondary analysis, data analysis followed Miles, Hubermann, & Saldana [11,40–43], using the full data set to develop the codebook. First-cycle coding was deductive and focused on highlighting excerpts of students' perceptions of themselves as interdisciplinary scholars, their desires to become them, and their perceptions of their abilities to attain that status based on initial code definitions developed in an earlier analysis of the data [8–10].

The second cycle then used inductive coding to establish progression markers within each dimension. Through collaborative analysis and team discussion, we developed a spectrum of developmental codes for each dimension, shown in Table 1.

Table 1: Operationalization of Future Possible Selves Framework Interdisciplinary Development

| Code	Definition
Primary Code – *Self-Perceived Interdisciplinary Scholar Development Progress*: captures students' self-assessment of their progress toward becoming interdisciplinary scholars on a continuum from not perceiving any progress to fully identifying as an interdisciplinary scholar.	
Not in Progress	The student does not perceive themselves as making any progress towards becoming an interdisciplinary scholar or incorporating interdisciplinary approaches into their work.
In Progress (far)	The student acknowledges that they are working towards becoming an interdisciplinary scholar, but they perceive themselves as being relatively early in that journey.
In Progress (close)	The student recognizes that they are making significant progress towards becoming an interdisciplinary scholar and perceives themselves as being relatively close to attaining that status.
Attained Status	The student identifies themselves as an interdisciplinary scholar.
Primary Code – *Desire*: the extent to which STEM grad students want to develop an identity as an interdisciplinary researcher or practitioner	
Does not want to be	The student explicitly expresses a lack of desire to become an interdisciplinary scholar.
Unsure	The student is uncertain or undecided about whether they want to be an interdisciplinary scholar.
Wants to be	The student expresses a clear desire to become an interdisciplinary scholar.
Primary Code – *Possibility*: The degree to which STEM grad students consider it possible to attain status as an interdisciplinary researcher or practitioner	
Not possible to attain	The student believes it is not possible for them to attain the status of an interdisciplinary scholar.
Unsure if possible	The student is uncertain whether attaining interdisciplinary scholar status is a realistic possibility for them.
Possible to attain	The student views attaining interdisciplinary scholar status as an achievable possibility for them.

Analyzing Development via Pattern Coding and Visualizing Trajectories for Thematic Analysis
Following codebook development and final coding of all interviews from all eleven students, we employed pattern coding [11] and thematic trajectory analysis [12]. This analysis involved four distinct analytical phases.

Phase 1: Code Reconciliation: First, because some interviews included multiple codes within a given domain (e.g., an excerpt indicating desire to be interdisciplinary and an excerpt indicating uncertain desire), to ensure reliable trajectory analysis, we developed a systematic reconciliation protocol for interviews that contained multiple codes within the same dimension. For straightforward cases where one code appeared substantially more often than others, we applied a frequency threshold approach. For cases with equal representation of competing codes, we examined the context of excerpts and the alignment with adjacent data points and reached consensus about the overall status represented in the interview.

Phase 2: Temporal Matrix Construction: We then constructed time-ordered meta-matrices [41], illustrated in Figures 1-3, for each participant, to map status by year. These matrices visually represented how self-perception, desire, and perceived possibility evolved longitudinally.

Figures 1-3: Integrated Development Time-Ordered Meta-Matrices for Students 1-3
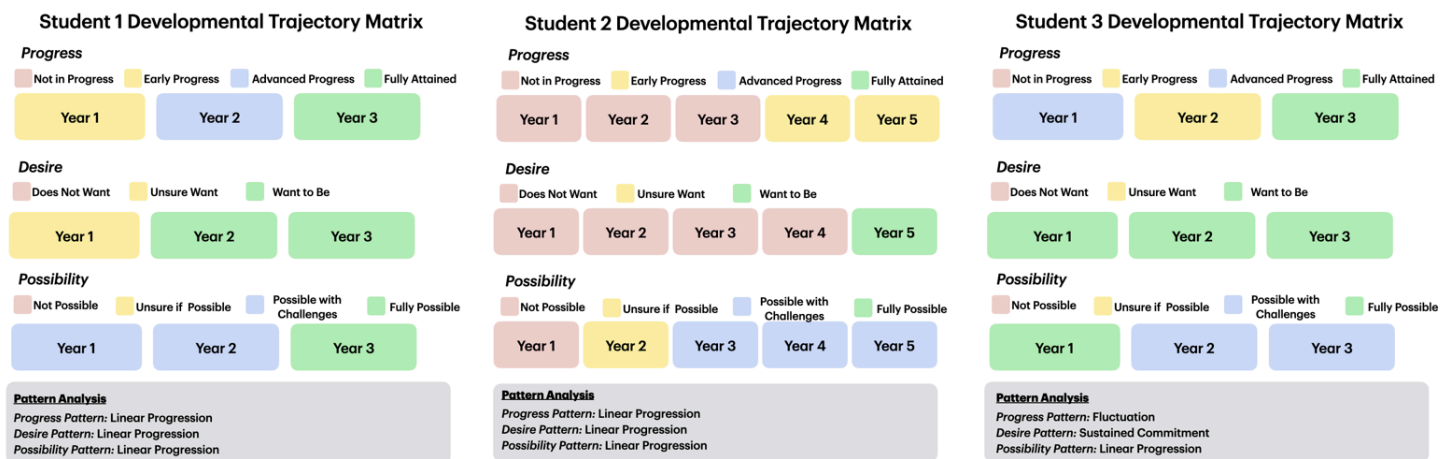
Phase 3: Trajectory Visualization and Thematic Trajectory Analysis: Following matrix construction, we employed thematic trajectory analysis techniques to analyze and visualize developmental patterns. We examined individual student trajectories using the time-ordered meta-matrices to identify trajectory patterns for each dimension separately, as well as patterns of interaction across the trajectories. To scope this paper, we focus on the latter - how the three dimensions interacted with one another over time; details on all of the patterns within each dimension are available in Webb's (one of the authors of this study) dissertation [44]. This effort enlightened the participant selection for this paper's focus on three students.

**Findings: Overview of Developmental Patterns**

Our analysis yielded the three interaction patterns: (1) ***Growth Alignment***: all dimensions showed coordinated growth. For example, students showed increasing self-perceived progress while maintaining desire and a growing sense of possibility. (2) ***Mixed Progress***: changes in one dimension differed significantly from changes in the other dimensions. For example, some students' self-perceived status fluctuated while desire remained. (3) ***Transformation Alignment***: movement from complete resistance to acceptance across all three dimensions, with at least one dimension showing a sharp change.

The following sections describe the three developmental patterns, using a single representative case for each pattern, demonstrating how dimensions of development emerge separately and then how they interact over time to create distinctive developmental trajectories.

Case 1: Student 1 - The Growth Alignment Pattern

As seen in Figure 4, Student 1's developmental trajectory exemplifies the Growth Alignment Pattern, characterized by coordinated growth across all three dimensions of self-perceived progress, desire, and perceived possibility and culminating in identification as an interdisciplinary scholar. Their journey demonstrates how initial tentativeness about interdisciplinary work can evolve into a confident interdisciplinary identity through sustained engagement with interdisciplinary practices and communities.

Figure 4: The Growth Alignment Pattern Developmental Trajectory

Growth Alignment Pattern
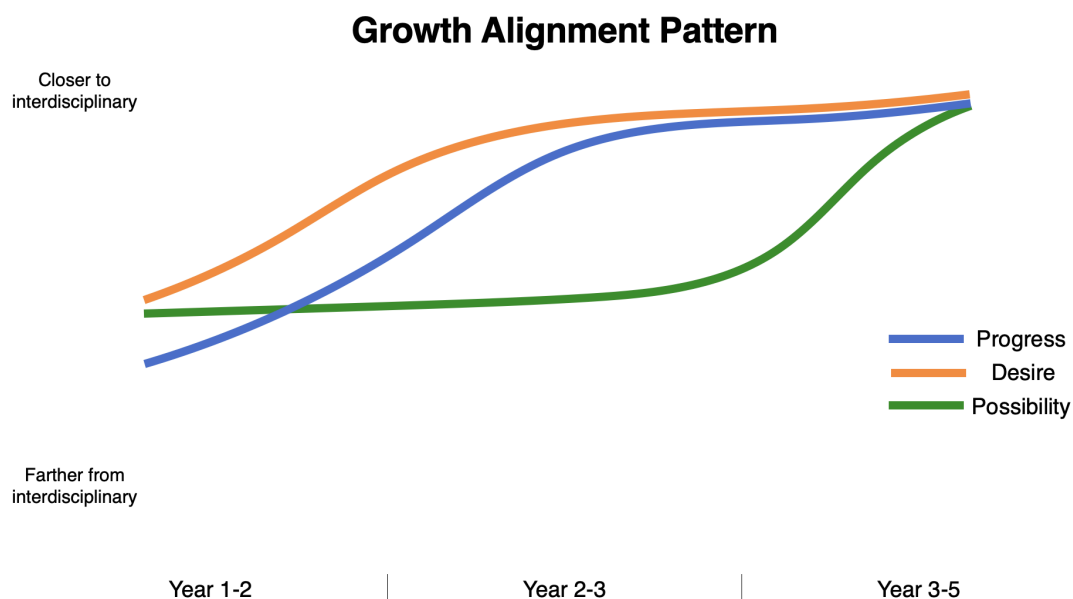
Desire Trajectory

Student 1's desire to pursue interdisciplinary work showed an interesting evolution from initial hesitancy to strong commitment. In Year 1, they expressed ambivalence: "To some extent, I want to be an interdisciplinary scholar, but I don't want that to be my title." However, by Year 2, this hesitation transformed into a clear aspiration: "I definitely want to be an interdisciplinary scholar...I want to push my discipline this way in the future." By Year 3, their desire manifested as a commitment to continuing interdisciplinary work post-graduation: "I feel like I am and will continue to be an interdisciplinary researcher/professional where I'm looking to use the concepts and stuff that I've learned...while also learning new concepts along the way."

Perceived Possibility Development

The evolution of Student 1's perception of possibility reflects growing confidence tempered by a realistic understanding of challenges. Their trajectory moved from seeing interdisciplinary work as "possible but challenging" in Year 1 and Year 2 to viewing it as clearly "possible" in Year 3. Early interviews acknowledged structural barriers: "It's a challenge because the field is only just

starting to think about these issues and some people push back on them." However, by Year 3, they expressed confidence while maintaining awareness of institutional contexts: "I think things have started and are changing already to make these career pathways more viable. We see it with just the IDR program existing."

Self-Perceived Progress Evolution
In Year 1, Student 1 positioned themselves as being in early stages of interdisciplinary development, explicitly acknowledging their limited expertise when describing their perceived progress: "In terms of my discipline, I would say I'm probably like a 5 [on a scale of 1-10]... And as far as interdisciplinary, I would say probably like a 2 or a 3, because... I've still got a lot more research and stuff in other disciplines to better understand." This initial self-assessment reflected both recognition of their disciplinary foundation and awareness of room for interdisciplinary growth.

By Year 2, their perceived progress showed marked progression toward interdisciplinary identity: "I feel like pretty much all of my research is interdisciplinary... I'm aligned with interdisciplinary work in my field because of how it addresses social justice, and I see myself as a scholar in that way now and going forward." This shift indicated growing confidence in integrating interdisciplinary approaches within their core engineering work.

Their trajectory culminated in Year 3 with full identification as an interdisciplinary scholar: "I definitely see myself as an interdisciplinary researcher because all the different methods that I'm using are outside of engineering."

Integrated Analysis
In a sense, Student 1 embodies the kind of ideal growth many interdisciplinary programs both imagine and desire. Student 1's case illuminates how the alignment of these three dimensions created mutually reinforcing development. Their growing self-perception as interdisciplinary coincided with strengthening desire and increasing sense of possibility, creating positive feedback loops. This alignment appeared particularly important in helping them navigate tensions between disciplinary training and interdisciplinary aspirations - a key challenge for STEM graduate students noted in previous research. Their trajectory also reveals the importance of connecting interdisciplinary identity to broader professional purpose. Student 1 increasingly linked their interdisciplinary development to goals of serving communities, suggesting how finding meaningful applications for interdisciplinary work can strengthen identity formation.

Case 2: Student 2 - The Transformation Alignment Pattern
Student 2 provides a useful illustration of the Transformation Alignment Pattern because they participated in an interview for each of their five years in the program. Their developmental trajectory, shown in Figure 5, illustrates a transformation from sustained resistance in both desire and progress to abrupt engagement with interdisciplinary identity, demonstrating how initial opposition can evolve through extended program participation.

Figure 5: The Transformation Alignment Pattern Developmental Trajectory

Transformation Alignment Pattern
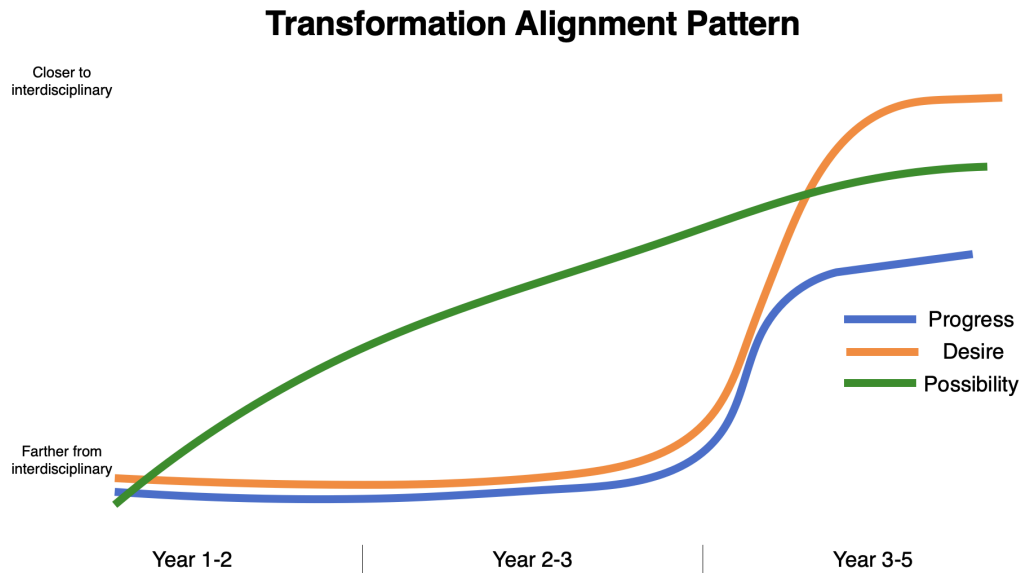
Desire Trajectory

The evolution of Student 2's desire to pursue interdisciplinary work demonstrates perhaps the most dramatic transformation. Initially, they expressed explicit rejection: "I don't really want to. It's something I've struggled with the entire year… interdisciplinary was never one of my goals" (Year 1). This resistance persisted through the years, with consistent expressions of preference for disciplinary work through Year 4. However, by Year 5, a remarkable shift occurred in their desire orientation: "I want to help be part of the interdisciplinary thinking that can help with these problems." This transformation reflected a deeper understanding of interdisciplinary work's value.

Perceived Possibility Development

Unlike the sharp turns in progress and desire after their third year in the program, Student 2's perception of possibility underwent a more gradual evolution, from "not possible" in Year 1 ("becoming an interdisciplinary scholar feels impossible") through stages of uncertainty between Years 2 and 3 to eventually seeing it as "possible but challenging" in Year 3-5. Their evolving assessment reflected growing sophistication in understanding both opportunities and constraints: "I feel like it is possible to go from a disciplinary researcher to an interdisciplinary one. I'm a testament to that" (Year 5). This progression in perceived possibility appeared to facilitate their broader transformation, suggesting how shifts in one dimension may catalyze changes in others (though a full explanation of causal interactions is beyond the scope of this paper). However, their recognition of possibility remained consistently tempered by awareness of institutional barriers, particularly within engineering contexts.

Self-Perceived Progress Evolution

Student 2's self-perception remained firmly anchored in "not in progress" status for their first three years (Year 1-Year 3), reflecting strong initial resistance to interdisciplinary development. Their Year 1 positioning was unequivocal: "I'm not exactly cross-disciplinary. I'm not trying to be." This resistance persisted through Year 3, with consistent articulation of disciplinary rather

than interdisciplinary identification. However, by Year 4, their self-perception showed meaningful progression to "in progress (far)," indicating nascent recognition of interdisciplinary development: "Between a 3 and 4 and a half out of ten. I feel like I am making progress, but still new, and it's a big challenge ahead of me." This shift represented a significant transformation from their earlier categorical rejection of interdisciplinary identity.

Integrated Analysis
Student 2's case illuminates a couple of critical aspects of interdisciplinary identity development: (1) *Non-Linear Development:* Their trajectory challenges assumptions about linear progression, demonstrating how sustained resistance can precede meaningful transformation. (2) *Role of Time:* The extended period of resistance before transformation suggests the importance of sustained exposure and engagement, even when initial responses are negative. Their case offers valuable insights for supporting graduate students, suggesting the importance of allowing space for resistance while maintaining opportunities for engagement. The transformation pattern also demonstrates how initial opposition need not preclude eventual meaningful engagement with interdisciplinary identity.

Case 3: Student 3 - The Mixed Progress Pattern
Student 3's developmental trajectory, shown in Figure 6, illustrates a more complex, non-linear path toward interdisciplinary identity formation, characterized by apparent regression in self-perceived progress while maintaining strong desire and evolving perceptions of possibility. Their case illuminates how deeper engagement with interdisciplinary work can lead to more nuanced, and sometimes seemingly contradictory, patterns of development.

Figure 6: The Mixed Progress Pattern Developmental Trajectory

Mixed Progress Pattern
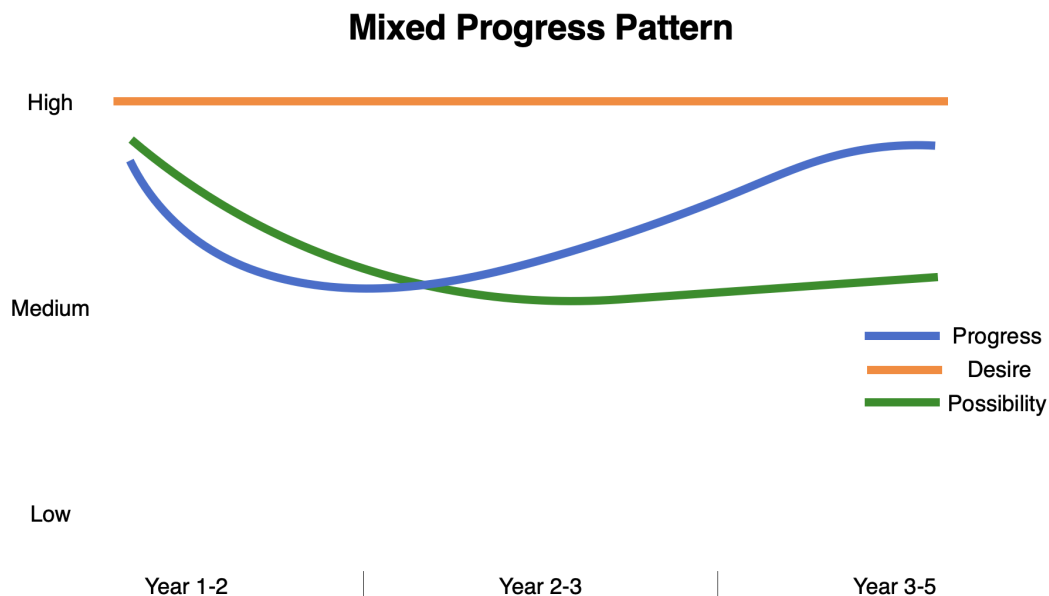
Desire Trajectory
While their progress went back before moving forward, Student 3 maintained a consistently strong desire to pursue interdisciplinary work, though here, too, their understanding of what this

meant evolved. In Year 1, they articulated clear aspirations: "I want to be able to communicate to folks from other disciplines. I want to be able to understand them as well as help them understand what I do." This fundamental desire remained stable even as their understanding of interdisciplinary work's complexity grew and consequently, their desire moved from communication to deeper engagement with interdisciplinary thinking: "I think there's a lot of justification for the movement for interdisciplinary research and education... I want to be in that interdisciplinary space." (Year 3).

Perceived Possibility Development
Student 3's perception of possibility also showed interesting evolution– from straightforward "possible" in Year 1 to "possible but challenging" in Year 2 and Year 3, reflecting growing recognition of institutional constraints. Their early confidence - "I know that I am capable of learning on my own outside of my discipline as needed to maintain my interdisciplinarity" (Year 1) - evolved into more nuanced understanding of structural challenges: "It is challenging for engineering faculty to make time for interdisciplinary work when they don't get credit for it in the same way as disciplinary" (Year 3). This change reflects a growing awareness of the practical realities of working across disciplinary boundaries as an engineering faculty member.

Self-Perceived Progress Evolution
Student 3's self-perception moves from "in progress (close)" in Year 1 to "in progress (far)" in Year 2, before ultimately reaching "attained status" in Year 3. This apparent regression reflected a deepening understanding of interdisciplinary work's complexities. In Year 1, they expressed confident positioning: "I feel like my work itself is interdisciplinary. So in some ways I feel like I'm already an interdisciplinary scholar just because that's my research." However, by Year 2, this confidence gave way to more nuanced self-assessment: "I still feel like I have a primary home and am just pulling little pieces of other disciplines, not deeply in them like I should be if I am really interdisciplinary." This shift represented not diminished capability but rather a more sophisticated recognition of interdisciplinary work's demands, because by Year 3, their self-perception evolved to full identification as an interdisciplinary scholar, but with sophisticated understanding of its implications: "I think I used to think I was an interdisciplinary scholar, and now I think I'm more so...because of IDR, I'm forced to think about problems not just in an engineering way of thinking but who is it for," emphasizing the value of engaging with social scientists from a range of disciplines to understand technical problems more fully in context.

Integrated Analysis
Student 3's case also illuminates several critical issues: (1) *Non-Linear Progress:* Their mixed-progress trajectory, like transformational alignment, challenges assumptions about linear development, showing how apparent regression can reflect deeper understanding. (2) *Sophisticated Understanding:* Their journey reveals how growing comprehension of interdisciplinary complexity can still sustain and even strengthen commitment to interdisciplinary identity. This provides insight for supporting graduate students' interdisciplinary development, suggesting the importance of recognizing that apparent setbacks may represent important developmental progress. Sustained desire and evolving understanding can support successful interdisciplinary identity formation even through periods of apparent regression.

Discussion

Our analysis extends existing understanding of how developing scholars navigate the complex terrain between disciplinary and interdisciplinary identities and builds on Holley's [28] findings by identifying multiple distinct developmental patterns. Borrego & Creamer [17] found that interdisciplinary collaborators often have more in common than differences, but our longitudinal analysis reveals how these commonalities may develop through distinct trajectories. Similarly, extending Baker & Lattuca's [32] research on the networked nature of graduate student identity development, our work reveals a process of identity reconstruction that engages students' understanding of both themselves and their place within their academic or professional communities. Finally, as Boden et al. [45] argue, high-consensus fields present distinct challenges for interdisciplinary identity development due to their tightly defined epistemological boundaries, and these boundaries are often what contributed to students' perceptions of both possibility and desire.

These findings have several implications for graduate education practice and policy. (1) *Need for Flexible Support Structures:* Our study suggests the need for support systems that can accommodate multiple valid developmental pathways. This requires moving beyond one-size-fits-all approaches to recognize and legitimize different trajectories toward interdisciplinary scholarship. (2) *Reframing Regression as Development:* Our findings challenge linear models of development by demonstrating how apparent regression may actually represent sophisticated progression in understanding. This reframing includes showing how increased understanding of complexity can manifest as temporary setbacks in self-perceived progress. (3) *Sustained Development Support Supporting:* Following Newswander & Borrego's [3] emphasis on long-term engagement, our findings also demonstrate the importance of sustained support throughout the developmental process. The identification of different temporal patterns suggests that brief interventions may be insufficient for supporting meaningful identity transformation.

Limitations and Suggestions for Future Research

While this study provides valuable insights into STEM graduate students' interdisciplinary identity development trajectories, several limitations warrant consideration and suggest directions for future research. (1) *Secondary Data Analysis Limitations:* Although the SHARE framework [36] guided our secondary analysis, the data were not explicitly collected to address this research question. While the interview protocol yielded rich longitudinal data, targeted protocols might have revealed additional nuances. (2) *Temporal Resolution:* The annual interview frequency of the data potentially obscures interim fluctuations in students' identity development. More frequent data collection at the semester level, particularly in the early years, might reveal micro-developmental patterns and transition moments not captured in yearly intervals, but of course, it imposes additional burdens on participants [12]. (3) *Sample Considerations:* Data were collected from a single program at a single study site; though the site is characteristic of many public R1 institutions nationally, and participants came from a variety of departmental backgrounds, transferability is limited to similar contexts and the data set limits the ability to examine how varying institutional structures might influence development patterns.

From a methods perspective, future studies would benefit from more frequent data collection points to capture fine-grained developmental patterns, as well as extended tracking to follow students' pathways after graduation. The development of mixed methods incorporating quantitative measures, along with comparative studies across multiple institutions and programs, could provide broader insights into trajectories. *From a contextual standpoint*, future research

should explore comparative studies across different types of programs, investigate how varying institutional structures influence development patterns, and examine how different STEM disciplines might present unique challenges for interdisciplinary development.

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