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Shaping mathematics identity: An exploratory study on specifications grading in Calculus I at a Hispanic-Serving institution

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Abstract

Calculus I courses play a pivotal role in shaping students' STEM pathways, making it essential to adopt pedagogies that foster both achievement and mathematics identity development, particularly among underserved groups such as Hispanic students. This study explores the impact of Specifications Grading, an alternative assessment method where students meet specific course learning objectives through multiple attempts, on students' mathematics identity development. Through a comparative case study of two Calculus I students at a Hispanic-Serving Institution, one enrolled in a specification graded course and the other in a traditionally-graded course, we examine shifts in their self-perceptions of competence, interest, recognition in mathematics, and overall mathematics identity. Our findings suggest that specifications grading can enhance students' mathematics identity by encouraging perseverance and a sense of competence. This study contributes to the field of mathematics education by providing empirical evidence that alternative assessment structures, like specifications grading, can serve as powerful tools for creating more equitable and identity-affirming learning environments in foundational STEM courses.

Keywords: Alternative Assessments, Calculus, Hispanic Serving Institution, Mathematics Identity, Specifications Grading

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Mathematics poses a significant academic challenge for many students (Weisburst et al., 2017), including historically marginalized groups like Hispanic students. Despite progress in expanding access to mathematically oriented degrees, many Hispanic students still underperform in key introductory college mathematics courses compared to their White peers (Ives & Castillo-Montoya, 2020; Solórzano et al., 2013). While underrepresented students can succeed in college mathematics (Crisp et al., 2015; Porter & Byrd, 2021), systemic barriers like these continue to prevent many of them from completing degrees in mathematics and other STEM fields. Calculus I holds particular significance as a high-stakes course that often determines students' continuation in STEM majors (Norton et al., 2017). Its reputation as a “gatekeeper” stem not only from the complexity of the content, but also from the rigid structures of instruction and assessment that often dominate its delivery. For historically underserved students, particularly Hispanic students, these rigid structures can create barriers to persistence, as failure rates are significantly higher than for their White peers (Convertino et al., 2022). However, research has demonstrated that fostering mathematics educational spaces in which students develop a stronger mathematics identity may positively impact their mathematics perseverance and overall success (e.g., Fernández et al., 2022; Gonzalez et al., 2022; Matthews, 2020; Rainey et al., 2018). Similarly, non-traditional teaching environments have been shown to correlate with increased belonging and desire to continue in STEM (Rainey et al., 2019). Combined, these insights highlight the importance of addressing structural classroom factors in promoting the development of mathematics identities.

By examining mathematics identity development in the context of Calculus I, we intentionally focus on a course that functions as a critical decision point in students' STEM trajectories. Thus, our study offers insights not only into identity development but also into how rethinking pedagogical design in Calculus I, especially through specifications grading, can support more equitable pathways for underrepresented students in mathematics-intensive fields. Identity, in this context, can be understood as a social construct in which individuals define themselves based on their beliefs, values, and social interactions (Marcia, 1980; Waterman, 1984). Marks and Mahoney (2014) further distinguish between social identities, or how one identifies in relation to others (e.g., being Latino, a Christian, or an Eagles fan), and personal identities, or how one identifies as different from others (e.g., being charismatic, loyal, or hard-working). In other words, while some forms of identity may be based on an individualistic development through self-reflections and experiences, a social identity is believed to be embedded in and formed within a social context (Gee et al., 2001). In the realm of science education, Carlone and Johnson (2007) applied these ideas to explore the science identities of women of color. In this model, the effect of one's race, gender, and ethnicity on one's science identity development was explicitly considered. Results demonstrated that individuals with strong science identities self-reported having a strong knowledge and understanding of science content, tools, and procedures (i.e., aspects of personal identities) while also feeling recognized as a "science person" by others (i.e., aspects of social identities).

Drawing from this and other similar research (e.g., Carlone & Johnson, 2007; Cass et al., 2011; Hazari et al., 2010), Cribbs et al. (2015) developed an explanatory model for mathematics identity. Adams (2018) defines mathematics identity as "the dispositions and deeply held beliefs that students develop about their ability to participate and perform effectively in mathematical contexts" (p. 121). Cribbs et al. (2015) further categorizes math identity into three interconnected subconstructs: mathematics interest, recognition, and competence/performance. Interest reflects students' motivation and curiosity to engage with mathematics, recognition involves how others perceive them in relation to mathematics, and competence/performance combines their self-beliefs about mathematics understanding and ability. Building on these perspectives, it becomes evident that mathematics identity involves an interrelation of personally- and socially-based identities grounded in the extent to which individuals see themselves as competent mathematics doers while also being socially accepted and recognized as members of such discipline (Gardee & Brodie, 2023). Therefore, fostering learning environments that encourage interest, recognition, and competence/performance may help students see themselves as capable and valued participants in mathematics.

We posit specifications grading (Nilson, 2015) provides opportunities for students to develop their interest, recognition, and competence/performance in mathematics. In traditional mathematics classrooms, assessments often focus on exams and quizzes, where final grades leave little room for improvement or reflection. In contrast, specifications-graded courses, a form of alternative grading methods, identify a set of Learning Targets (also known as course learning objectives) from the course and students are encouraged to master these through multiple attempts (Nilson, 2015). Additionally, rather than granting full or partial points for assessments, students are provided with specifications on assignments that describe "mastery" or "approaching mastery" progress toward the Learning Targets. For example, specifications in mathematics courses may include solving specific types of problems or meeting certain criteria in mathematical proofs. Letter grades of "A, B, C, D, F" are then assigned as semester grades depending on the number of Learning Targets met. In this manner, students are aware of the grading system at the beginning of the semester and have the knowledge to determine the letter grade they aim to achieve based on the workload. As a result, students are held to higher academic standards where mastery is the goal, are motivated to learn and excel via multiple assessment opportunities and have an overall greater agency over their own grades (Nilson, 2015; 2016).

We argue that implementing specifications grading in a mathematics course like Calculus I is ideal for fostering stronger mathematical identities as it allows students to reconsider what it means to participate and perform effectively in mathematical contexts. For instance, instead of being confined to proving mathematical mastery across a limited number of chances with singular attempts, students in specifications-graded courses receive continual feedback and opportunities to exhibit mathematical maturity throughout an academic semester. This, in turn, can reshape students' perceptions into thinking about mathematical proficiency as obtainable through perseverance rather than through innate talent and therefore allowing them to identify more with those ideals (i.e., an overall stronger mathematics identity). Indeed, specifications grading has been shown to provide students with a sense of growth as they obtain greater control over their mathematical trajectories, resulting in a more authentic and equitable reflection of their proficiency in their respective courses (e.g., Boesdorfer et al., 2018; Katzman et al., 2021; Stange, 2016; Talbert, 2017; Tsoi et al., 2019). Unfortunately, empirical research on specifications grading, including how it relates to students' mathematics identity development, remains significantly unexplored (Beatty, 2013; Post, 2017; Toledo & Dubas, 2017). We posit that research on growth mindset (Dweck, 2006) may offer insights into this relationship between specifications grading and mathematics identity.

Growth mindset theory (Dweck, 2006) provides a framework for understanding how specifications grading can influence students' mathematics identity. Dweck (2006) defines mindset as students' perceptions of their own abilities and intelligence. These can fall on a spectrum between a fixed mindset and a growth mindset, where possessing a growth mindset positions one's abilities and intelligence as malleable and improvable. Research has shown that a growth mindset boosts students' academic achievement (Boaler, 2013; Yeager et al., 2019), improves students' resilience (Yeager & Dweck, 2012), mitigates poverty's effects on academic achievement (Claro et al., 2016), reduces students' mathematics anxiety (Samuel & Warner, 2021), and increases students' self-efficacy in mathematics while also decreasing course dropout rates (Shoshani, 2021). In contrast, students with a fixed mindset often avoid challenges and achieve less academically (Dweck, 2006). Most alarmingly, Limeri et al. (2020) found that constant academic struggle reinforces a fixed mindset, creating a cycle of lower performance and diminished confidence.

Because specifications grading offers students multiple attempts to meet Learning Targets through written feedback on assessments and seeking extra help from others, we hypothesize that instructors' use of specifications grading may foster the development of stronger growth mindsets among students as this approach presents academic struggles not as signs of failure but as part of the learning process that can be overcome. This, in return, can increase students' self-efficacy and sense of competence in doing mathematics and, ultimately, influence their overall mathematics identity development (see Figure 1). Indeed, Sun (2018) identified fourteen teaching practices that can promote a growth mindset in mathematics classrooms, some of which are involved in giving feedback and assessing students. Sun asserted the practices of giving verbal praise, written feedback, and opportunities for extra help, in addition to having grading policies that offer opportunities for students to re-attempt their work, could promote students' growth mindset.

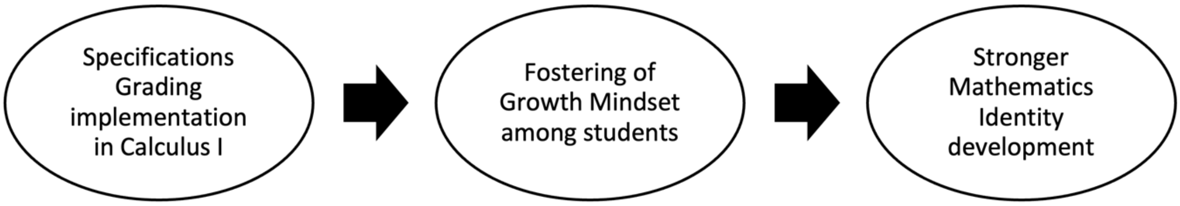

Figure 1. Hypothetical pathway from specifications grading in Calculus i to growth mindset development and its impact on mathematics identity formation

Although various alternative assessment methods, such as upgrading, have gained recent attention (Hackerson et al., 2024), we chose specifications grading for its unique blend of transparency, structure, and student agency. Unlike some models that rely heavily on subjective reflection or minimalist assessment, specifications grading offers repeated, clearly defined opportunities for students to demonstrate mastery while emphasizing formative feedback and revision (Donato & Marsh, 2023). This structure is especially well-suited for courses like Calculus I, where the stakes are high and failure often leads to attrition from STEM fields (Katzman et al., 2021). Furthermore, while there is a growing interest in alternative grading systems, few studies have empirically examined their role in shaping mathematics identity, particularly for historically marginalized populations. However, emerging research indicates that specifications grading, through its emphasis on mastery and opportunities for revision, can support the development of mathematical habits of mind and potentially foster a more inclusive learning environment (Prasad, 2020; Carlisle, 2020) Our study addresses this gap by investigating how specifications grading interacts with students' sense of competence, recognition, and interest in mathematics. Given the global imperative to broaden participation and retention in STEM (Prasad, 2020), especially among underrepresented and multilingual students (Civil & Hunter, 2015), this work offers insights into assessment design that can support more equitable and identity-affirming mathematics learning environments worldwide.

Given this theoretical foundation, our study explores how specifications grading may contribute to the mathematics identity development in Calculus I students. We adopted a comparative case study approach, examining the mathematics identity development of two students, one in a specifications-graded course and one in a traditionally-graded course. By comparing the changes in their mathematics identities, we aim to explore how specific elements of the two different pedagogical approaches affect their identity development. The research is guided by the following questions:

Research Question 1: How do two Calculus I students describe their mathematics identity development in the context of either a specifications-graded or traditionally-graded course?
Research Question 2: What course features do these students identify as influencing their mathematics identity development in their respective Calculus I experiences?

Through this investigation, we provide insights into how alternative assessment strategies like specifications grading can shape the mathematical identities of underrepresented students, offering broader implications for equity in mathematics education.

METHODS

Setting

We collected data at a large Hispanic-Serving Institution (HSI) in the southwestern United States, where over 90% of the student population identifies as Hispanic. In Spring 2022, the university offered 14 sections of Calculus I, enrolling approximately 500 students in total. While all sections adhered to a common departmental syllabus to ensure uniform content coverage, the instructional structures varied notably across sections.

Nine of the 14 sections, serving approximately 300 students, implemented a specification grading model. In these sections, the course was organized around 29 Learning Targets, each representing clearly defined course objectives aligned with core mathematical concepts. Student learning was assessed through a combination of weekly group worksheets, four major exams, and online homework assignments. Mastery of each Learning Target was evaluated on both the worksheets and exams. When students did not demonstrate mastery on a worksheet, they could revise and resubmit their work. Similarly, students who did not show mastery on an exam were allowed to schedule a retesting session for the specific Learning Target they had not yet passed. These retesting opportunities were available weekly on Fridays, beginning after the first exam and continuing through the end of the semester. Students received detailed, criterion-based feedback to guide revisions and promote learning through multiple attempts.

In contrast, the traditionally-graded sections employed a more conventional assessment approach, where final grades were determined by cumulative performance on quizzes, group work, exams, and homework. These assessments were primarily summative and typically did not allow for reassessment. Students received single-attempt evaluations, often scored using partial credit systems, and feedback was less targeted toward revision or mastery. Lastly, while all students, regardless of grading system, had access to the same institutional support services, such as faculty office hours, academic advising, and a campus tutoring center, engagement with these resources differed across course structures.

Survey Data Collection and Case Selection

This study is part of a larger project in which we surveyed Calculus I students at this HSI about their experiences in their mathematics courses and their mathematics identity. To facilitate our study, we administered Cribbs et al.'s (2015) validated 12-item mathematics identity survey instrument. Using a 5-point Likert scale, the survey assesses an individual's mathematics identity (survey item 4), including its three subconstructs: competence/performance (survey items 7, 8, 9, 10, 11, and 12), interest (survey item 1, 2, and 3), and recognition (survey items 5 and 6) in mathematics. Each item was rated on a scale ranging from one (1 ~ strongly disagree) to five (5 ~ strongly agree). This resulted in four scores through averaging, when applicable, which facilitated the comparisons within and across students (see Cribbs et al. (2015) for the list of survey items). In addition to these questions, demographic and supplementary questions also focused on the students' past experiences with college-level mathematics. These included questions on gender, race/ethnicity, primary language(s) spoken at home, academic classification, enrollment status, career goals, and prior Calculus experiences (if any). Students were also given the option to volunteer for a follow-up interview.

The survey was given during the second (i.e., pre-survey) and antepenultimate (i.e., post-survey) week of classes. The survey was taken by 218 students enrolled in Calculus I. Of these, 119 were enrolled in a course section implementing specifications grading. Most of the 218 students identified as primarily first-generation Hispanic students in STEM-related majors. Table 1 below summarizes the descriptive statistics for mathematics identity and its three subconstructs, competence/performance, interest, and recognition, based on the validated instrument by Cribbs et al. (2015). The table includes means, standard deviations, and changes from pre- to post-survey for both grading types. These quantitative results provide a broader context for the case studies by capturing the general trends in students' mathematics identity development across course structures.

Table 1. Descriptive statistics for Math ID and subconstructs by grading type and time point

Construct	Grading Type	M(Pre)	SD(Pre)	M(Post)	SD(Post)	Δ (Post – Pre)
Math Identity	Specifications Grading Cal I	3.27	1.03	3.34	1.00	+0.07
	Traditional Grading Cal I	3.33	1.03	3.29	1.05	–0.04
Competence / Performance	Specifications Grading Cal I	3.66	0.69	3.66	0.71	±0.00
	Traditional Grading Cal I	3.73	0.62	3.66	0.71	–0.07
Interest	Specifications Grading Cal I	3.62	0.82	3.56	0.85	–0.06
	Traditional Grading Cal I	3.67	0.82	3.57	0.83	–0.10
Recognition	Specifications Grading Cal I	3.15	0.82	3.23	0.82	+0.08
	Traditional Grading Cal I	3.18	0.82	3.18	0.81	±0.00

Among these 218 surveyed students, seven survey respondents volunteered for virtual semi-structured interviews (Drever, 1995) during the post-survey phase. Four (José, Victoria, Mario, Oscar) were in specifications-graded sections, and three (Antonio, Roberto, Carlos) were in traditionally-graded sections. We identified changes in the scores from the pre- and post-surveys for these seven participants. Figure 2 shows the radar charts showing the survey scores for the interest, recognition, competence/performance, and overall mathematics identity of the four students in the Calculus I specifications-graded courses. Figure 3 shows the radar charts for the three students in the traditionally-graded Calculus I courses. Each chart has the student's four survey scores plotted on the four axes. The orange region with a solid outline on the charts represents the students' pre-survey scores and the gray region with the dashed outline represents the post-survey scores.

Upon comparing the radar charts for students in specifications-graded courses versus those in traditionally-graded courses (both Figures 2 and 3, respectively), one can see that all students had increases in their mathematics identity score of at least 1 point except for Mario who was already at the maximum score. However, there were key differences in the changes of pre- and post-scores for students in specifications-graded courses and those in traditionally-graded courses. For competence and performance scores of the specifications-graded students, José had a minimal decrease, Mario had a minimal increase as he had a high score initially, and Victoria and Oscar had large increases in scores, whereas the traditionally-graded students had no change or a minimal increase of scores. For interest scores, José had approximately half a point decrease, Mario had no change given his already maximal score, and Victoria and Oscar had large point increases in scores that ranged from approximately 2 to 3 points, whereas Antonio had a minimal decrease, and Roberto and Carlos had a minimal 0.5- to 1-point increase in score. For recognition scores, all specifications-graded students had increases in scores. Both José and Mario had minimal increases of 0.5 to 1 point, and Victoria and Oscar had a larger increase in scores of 1.5 to 2 points. Alternatively, traditionally-graded students either had no change or had a minimal change in recognition scores without surpassing the 1-point threshold.

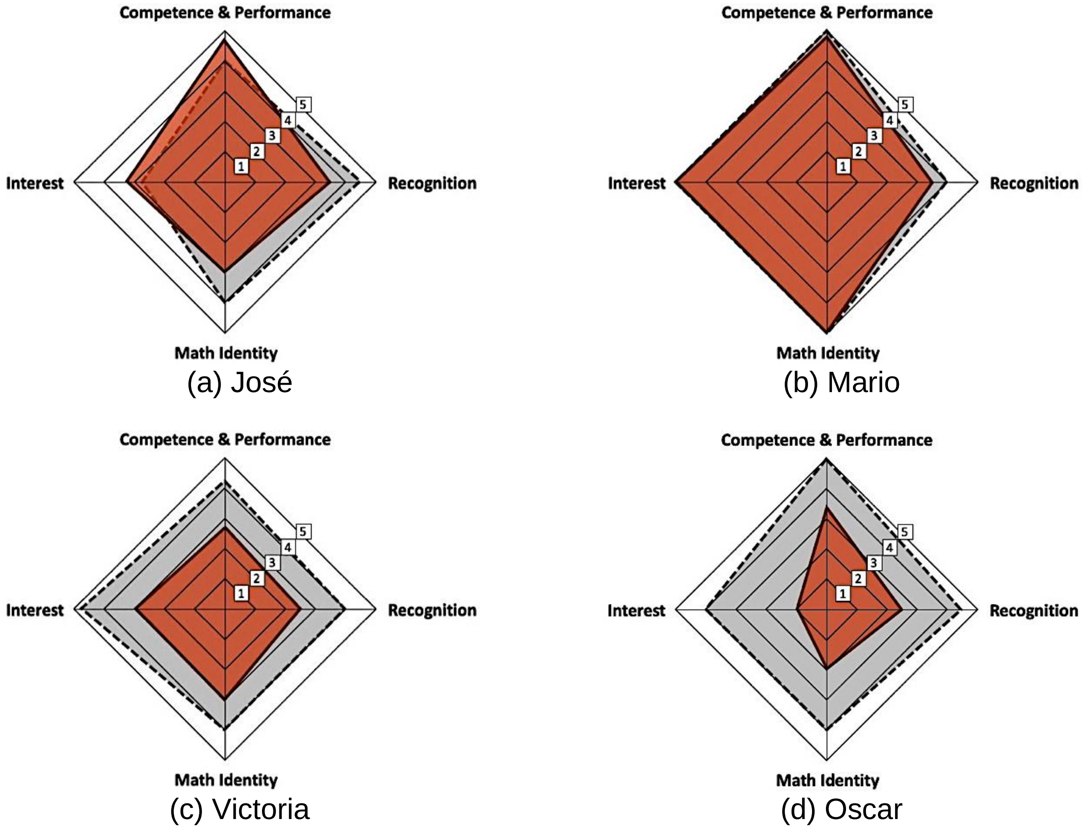

Figure 2. Radar charts showing pre- and post-survey changes in mathematics identity and its subconstructs (competence/performance, interest, recognition) for four students in specifications-graded Calculus I

These patterns in the case-level data are broadly consistent with the descriptive trends observed in our full dataset (see Table 1). Across this larger sample, students in specifications-graded sections showed consistent increases in overall mathematics identity (+0.07) and recognition (+0.08), while competence/performance remained unchanged (±0.00) and interest declined slightly (–0.06). In contrast, students in traditionally-graded sections exhibited more inconsistent changes, with small average decreases in mathematics identity (–0.04), competence/performance (–0.07), and interest (–0.10), with recognition remaining stable (±0.00). Although the individual case study participants often demonstrated more pronounced shifts than the average changes across the full sample, the directionality of change aligns students in specifications-graded courses generally reported more positive or stable outcomes, particularly in terms of how they saw themselves (i.e., math identity) and were recognized as mathematics learners (i.e., recognition). However, these quantitative results are offered solely for descriptive context and are not intended to support inferential or causal conclusions. Rather, they serve to illustrate how the trends observed in our focal cases reflect broader patterns in students' mathematics identity development across differing grading structures.

Combined, these results ultimately guided our selection of Oscar and Carlos for further investigation. Both students began their Calculus I course with the lowest mathematics identity scores, including low scores in interest, recognition, and competence/performance. However, at the end of their Calculus I course, they both had differing mathematics identity scores. Oscar, in the specifications-graded course, showed major increases of 2 or more points in his mathematics identity scores, while Carlos, in the traditionally graded course, exhibited minor increases of 1 point in his mathematics identity scores like other students in the traditionally-graded courses.

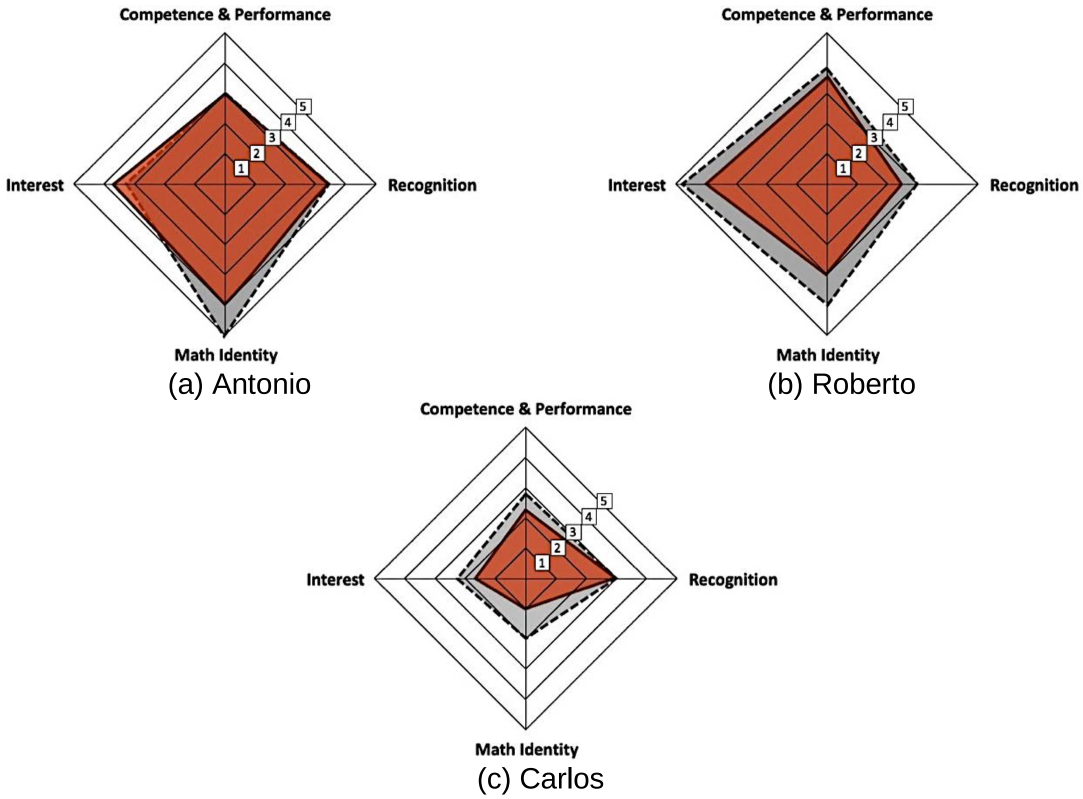

Figure 3. Radar charts showing pre- and post-survey changes in mathematics identity and its subconstructs (competence/performance, interest, recognition) for three students in traditionally-graded Calculus I

This case selection process was informed by Seawright and Gerring's (2008) types of case studies: "typical, diverse, extreme, deviant, influential, most similar, and most different" (p. 296). We used the most similar case selection method, where the cases we chose were most "similar on all the measured independent variables, except the independent variable of interest" (Seawright & Gerring, 2008, p. 304), which is the type of grading used in their Calculus I course. Therefore, to reduce the influence of confounding variables, we selected two participants who closely matched on key demographic and academic variables, such as major, academic year, ethnicity, bilingual status, and prior Calculus experiences. In that regard, Carlos and Oscar were similar in that they both identified as bilingual male Latinos who were Junior undergraduate Engineering majors at the same HSI. They both had equal access to institutional support services such as tutoring centers, academic advising, and office hours. Additionally, they both previously withdrew from their Calculus I courses due to low grades; Oscar was on his third attempt to pass Calculus I, and Carlos was on his second attempt to pass. They also described similar negative experiences in their prior Calculus courses. As such, these two cases presented a theoretically interesting contrast, where they exhibited differences in the independent variable (the type of grading used in their course) and the dependent variable of interest (their mathematics identity scores). In other words, the key contrast between the two students' experiences centered on the grading structure of their Calculus I courses, thereby strengthening the internal validity of our case comparison.

While this approach offers detailed insights into students' experiences, it also presents limitations in terms of generalizability. The findings from two individual cases are not intended to represent the broader student population. Rather, the goal is to inform theory and pedagogy through nuanced, context-specific analysis that highlights the complexity of identity development in relation to classroom structures. This is consistent with the aims of case study research, which prioritizes depth over breadth (Bromley, 1986; Yin 2003). Furthermore, as a qualitative study, we did not employ statistical tests to establish general patterns or correlations; instead, we used established frameworks (Cribbs et al., 2015) and systematic coding procedures to trace the participants' identity trajectories. The detailed narratives and pre-post survey comparisons offer illustrative rather than predictive power. Future research could extend these findings by incorporating a larger sample of students, utilizing mixed methods approaches that combine qualitative interviews with quantitative analyses to examine broader trends across instructional contexts. Such work would provide complementary perspectives and enhance the generalizability of findings related to specifications grading and mathematics identity development.

Interview Data Collection

Given that one's mathematics identity is personal and internal to an individual, we designed our semi-structured interviews (Drever, 1995) to elicit evidence of aspects of participants' mathematics identities through the provision of opportunities for them to tell narratives about their experiences in doing mathematics. This aspect of our interview protocol design was informed by narrative identity theory (Singer, 2005), which posits that individuals understand and construct their identities, in part, through the act of organizing and interpreting life experiences into coherent and meaningful stories that they share with others. It is through narrative identity that people "convey to themselves and to others who they are now, how they came to be, and where they think their lives may be going in the future" (McAdams & McLean, 2013, p. 233). When crafting the life stories that define their identities, individuals engage in a process of meaning-making as they reflect on and interpret their experiences. They then assign significance to events and derive a sense of purpose or coherence from the narrative they construct, which informs their current identities. Through sharing their stories with the interviewers, the first and second authors, the participants could make sense of who they were in relation to being a "math person" and verbally convey aspects of their mathematics identity. As individuals construct their life stories, they engage in a process of meaning-making, reflecting on experiences, interpreting their significance, and drawing coherence and purpose from the events that have shaped them.

Guided by this theoretical lens, our interviews provided participants with opportunities to articulate their identities as "math people." For instance, students were asked to select words that described mathematics and to define what it means to know and do math. These initial reflective tasks served as accessible entry points for students to begin exploring how their identities in mathematics had evolved over time. From there, participants shared specific moments in their educational journeys that influenced their attitudes toward mathematics, moments of struggle, success, or transformation. By encouraging participants to tell their stories, we aimed to surface how they construct coherence in their mathematical trajectories and how instructional contexts, particularly specifications grading, may have shaped their evolving sense of self in relation to mathematics.

The interview protocol also contained prompts that asked them about the three subconstructs of mathematics identity from Cribbs et al.'s (2015) study. For interest, students were asked to reflect on their enjoyment of mathematics and whether their Calculus I course increased their motivation to pursue further math-related studies. For competence and performance, participants discussed their confidence in understanding mathematics, handling setbacks, and feeling prepared for assessments. For recognition, the interview explored whether students felt seen as "math people" by instructors, peers, and family, and probed how race, gender, and linguistic identity may have shaped these perceptions. Follow-up questions also examined whether these feelings had changed over the duration of their Calculus I course. This structure enabled the research team to trace identity development over time and to examine how specifications grading may influence each dimension of mathematics identity.

Interviews concluded with one task prompting participants to choose a Venn diagram that best described how they aligned with the identities of mathematicians, scientists, and STEM professionals (see Figure 4). This Venn diagram exercise, adopted from Wilson et al. (2023), further elicited evidence of participants' perceptions of themselves as mathematicians. Questions also guided participants to reflect on how certain aspects of their Calculus I course (e.g., specifications grading) might have influenced their mathematics identity. Follow-up questions were asked as needed for clarification and elaboration. Each interview lasted for approximately 90 minutes and were recorded and transcribed.

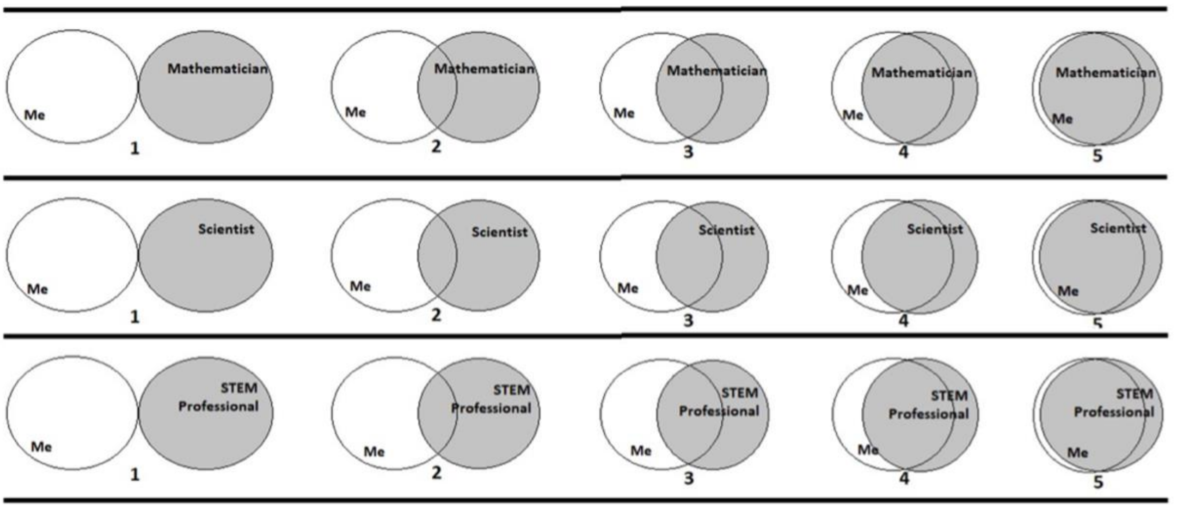

Figure 4. Venn Diagram task used in the interviews with participants (adopted from Wilson et al. (2023))

Data Analysis

The interviewers independently coded Carlos's and Oscar's interviews and met after each deductive and inductive coding process stage to reach an agreement on the differences in their coding. This coding process involved breaking down the data into small fragments to examine and compare for relations, similarities, and dissimilarities. We first used a deductive coding approach (Miles et al., 2013) using Cribbs et al.'s (2015) framework of the subconstructs of mathematics identity as prescribed themes to code the cases' references to interest, competence/performance, and recognition in the transcripts. Whenever the students' interview transcripts expressed their positive or negative emotions toward doing mathematics or taking subsequent mathematics courses, we coded the instance as indicative of "interest" and coded the instance as either positive (e.g., expressing enjoyment), negative (e.g., sharing feelings of hatred or frustration), or neutral. Whenever the participants' transcripts referred to their perceptions of their own (in)ability or (in)competence in doing mathematics, we coded the instance as "competence/performance" and again coded the transcript segment as either positive (e.g., "It looks like I'm having success"), negative (e.g., "It was all doom and gloom"), or neutral. In transcripts that referred to the participant's sense of others' perceptions of his mathematics ability, we coded the instance as "recognition," coded the type of recognizer (e.g., family, friends, current instructor, past teacher), and the quality of the recognition as positive, negative, or neutral. Throughout the entire coding process, we wrote analytic memos (Maxwell & Chmiel, 2013) about these coded instances to note whether the participants' responses were based on their experiences in their current Calculus course, prior college courses, or prior high school mathematics courses. This helped us characterize the nature of the participants' self-proclaimed changes in their interest, competence/performance, and recognition in doing mathematics over time.

In the inductive open coding stage of analysis (Miles et al., 2013), we coded aspects of the students' experiences in their courses (e.g., grading system, provision of tutoring, course format) to which they attributed their perceptions of their interest, competence/performance, and recognition in doing mathematics. As a result, we also coded for fixed and growth mindsets. Instances where participants expressed beliefs in the potential for personal growth and improvement were coded under "growth mindset," while instances where participants expressed beliefs in the static nature of abilities and limitations were coded under "fixed mindset." Further classification was made based on the context and nature of the statements. Additionally, the coding process involved examining participants' attitudes towards challenges, feedback, and learning opportunities to discern underlying mindset tendencies. We then wrote memos about how the coded aspects of the participants' course experiences and growth mindset seemed to influence each subconstruct of their mathematics identity. This allowed the research team to identify theoretical relationships between the participants' mathematics identity, growth or fixed mindset, and their course experiences, with or without specifications grading.

RESULTS AND DISCUSSION

Previous Calculus I Experiences

Survey responses given by Carlos and Oscar regarding their previous experiences in Calculus I shared some pedagogical similarities. First, they both experienced minimal lecturing time during their previous Calculus I coursework. Their previous Calculus I instructors focused more in-class time on covering example problems, as well as homework problems, all to prepare the students for upcoming quizzes and major examinations. In-class, individual student work was also kept to a minimum, including very limited time for students to work out problems on the board. Where these two experiences seemed to differ, however, is in the collaborative aspect of their respective former instructors and their courses. Carlos claimed his previous Calculus I instructor emphasized collaborative learning activities a lot more than Oscar's instructor. Carlos said his previous Calculus I course had plenty of opportunities for classroom discussions and collaborative assignments. Carlos also said he experienced more in-class time to work on assignment corrections, as opposed to Oscar, and an overall stronger connection between the material being covered and real-life scenarios and other subjects.

Pre- and Post-Mathematics Identity Survey on Current Calculus I Experiences

Radar charts of the participants' mathematics identity scores measured on the pre- and post-surveys provided in Spring 2022 for their current Calculus I class are in Figures 2 and 3. These charts illustrate the change in Oscar's and Carlos's scores, respectively, on the pre- and post-surveys. For example, Carlos, who did not participate in a specifications-graded course, had small increases in his mathematics identity, competence, and interest scores. His recognition score did not change at all, implying that Carlos had the same perception of others recognizing him as a mathematics person at both the beginning and end of his Calculus I course. Contrastingly, Oscar, who participated in a specifications-graded course, demonstrated large increases of one to three points in every measured score of mathematics identity and its subconstructs. As follows, we discuss the results from the analysis of participants' interview responses to unpack their mathematics identity development throughout their respective courses.

Semi-Structured Interview Results

Carlos's and Oscar's Perceptions of Their Competence and Performance in Doing Mathematics

One of the subconstructs of mathematics identity is the perception of one's competence and performance in mathematics. This subconstruct was measured with the following survey items: "I am confident that I can understand math," "I am confident that I can understand math outside of class," "I can do well on exams in this subject," "I understand concepts I have studied in math," "Others ask me for help in math," and "I can overcome setbacks in math." Oscar had a large increase in his competence and performance score from before and after his Calculus I course with specifications grading, and he exhibited the highest possible score in competence and performance (see Figure 2). Carlos had a minimal increase in his competence and performance score (see Figure 3), but in the interview, Carlos perceived a decrease in his sense of competence and performance during his traditionally-graded Calculus I course.

Carlos

Carlos self-reported a decrease in his sense of competence and performance from high school to his traditionally-graded Calculus I course. He claimed, "I'm doing these college courses, and they're more difficult, and there's not that much time… I'm struggling more to really grasp at it… specifically in math where I've been struggling the most." When asked about his perceptions of his confidence in doing and understanding mathematics, Carlos responded,

> *Not so much as I would like... I've been having trouble with remembering and knowing when to use specific formulas. They've been getting more obtuse or more kind of just a mix of things that just seems strange, and with not enough time to cover it, it just keeps getting stranger... I just don't really know what's happening right now, and most has to do with the formulas. That's been holding me down.*

Carlos's low perception of his abilities in doing mathematics seems to be rooted, in part, in the increased difficulty of college-level work. His specific challenges center around difficulties with mathematical formulas and the increasingly complex and unfamiliar nature of the content. It is possible to infer that, at that time, he perceived his own abilities as static or restricted as there is no explicit expression of motivation to persist despite these challenges. Carlos's feeling of being held down reflects a fixed mindset regarding his mathematical abilities, suggesting a resignation to perceived limitations and a lack of motivation to persevere through challenges.

Carlos also seemed to attribute his struggle to the quick pace of his Calculus I course, which often moved on to the next topic before he had a chance to fully comprehend the previous one. He compared this to his high school mathematical experience:

> *I didn't really struggle with math as much. But I guess it was a lot easier, back then, and we had more time, too. Even though we may not have liked it, we had more homework that would reflect what we did. And then moving on with college now, it's more fast-paced. It's*

> *been more of doing things on your own, reading a textbook, which I feel like that's not helping me at all with math, specifically.*

When we asked him what could have helped him better understand the material in his Calculus I course, Carlos responded, "I feel it's really just about giving it more time to slow it down and work things out better." Carlos claimed he did not struggle as much with mathematics in high school and felt "more confident about it" because he had "more time to understand the subject." This suggests a transition from feeling capable in high school to feeling overwhelmed in college, also possibly indicating a shift towards a fixed mindset regarding his mathematical abilities once at the college level.

Oscar

Oscar reported struggling in his prior mathematics courses and failing his Calculus I course, twice. Oscar referenced his prior Calculus I course experience as "a dooming failure," claiming,

> *You're just like – Well I'm never going to finish. This is not working. – and you know, all those red X's and stuff like that, it just puts you down, man. It puts you down. You're like – No, I don't want to do this anymore. It's not worth it.*

This suggests that Oscar may have initially held a fixed mindset about his mathematical abilities, indicating that he was not very confident about completing the course. He also mentioned feeling overwhelmed and unmotivated to address his past course setbacks, hinting towards the possibility that he may have felt like there were no more opportunities for growth.

However, this changed in Spring 2022 during his Calculus I course with specifications grading, as Oscar's sense of mathematical competence dramatically increased (see Figure 2). This increase was evident in the survey and interview data. He described his change in confidence: "You know I thought, like – *I'm never going to pass Calculus.* – Yes, you can. You can pass it if you put hard work and dedication to it. It is reachable." This illustrates a dramatic shift in Oscar having a fixed mindset and feelings of helplessness to having a growth mindset toward his competence and performance in mathematics. After this course, he perceived passing Calculus as "reachable" if he "put hard work and dedication" towards passing.

When asked about what specifically contributed to this change in his perceived competence and performance levels, Oscar highlighted key aspects associated with the course's use of specifications grading. For example, Oscar described having an unfair, demotivating grading system in his previous Calculus I course:

> *That was an unfair system of homework that just keeps bombarding you, and it keeps on demotivating you because all you see is like – Oh, you got one wrong, do 13 more, and if you get one wrong, 13 more then. – I found it kind of unfair and punishing, almost.*

According to Oscar, in his previous Calculus I course when students failed to solve a problem on their homework assignments, they were subjected to additional assignments, essentially regarded as a form of punishment. The type of homework system that Oscar experienced is called an adaptive system which adapts to students' learning based on their correct/incorrect responses. In traditional grading systems, students are typically given a single opportunity to pass assignments. Should they fail, they are not offered another opportunity for continued learning and improvement. Oscar referred to such traditional grading as "either you pass, or you don't pass… but then you're doomed." Because of this previous unmotivating grading policy, Oscar expressed appreciation for his current Calculus I provision of opportunities for him to persist in his multiple attempts to pass homework assignments and exams without requiring a considerable number of additional problems. He discussed the benefits of the specifications grading system as getting an opportunity to retest, claiming, "I love retest, love it. I'm doing that every Friday." This seems to have led to an improvement in his growth mindset, motivation for passing objectives, and his overall mathematical competence.

Oscar credited his improved mathematical competence to tracking his progress in successfully mastering Learning Targets. He explained, "You start seeing that you're making progress. That motivates you, and that amplifies your performance and gives you more confidence…it gives me confidence like – *Hey, I'm doing it!* – It's a boost to your confidence in your performance to do math." It seems that when he reflected on the Learning Targets he had already successfully passed, it acted as a source of encouragement for him. In other words, observing the growth of his achievements in this manner made him believe that he could continue to succeed in passing the Learning Targets if he persevered. In other words, seeing all the Learning Targets he passed seemed to help him have a growth mindset by thinking he could continue to succeed at passing the Learning Targets if he kept trying. This shift in mindset contributed significantly to Oscar's more positive perception of his competence and performance in mathematics. It not only bolstered his confidence but also served as a strong motivator to keep pushing forward.

Oscar also attributed his change in mathematical competence and performance to him seeing value in seeking assistance at tutoring centers. His specifications-graded Calculus I course required students to use campus tutoring resources in order to make up for missing Learning Targets, which led him to take advantage of them:

> *I go to tutoring every Thursday, and we went over three Learning Targets. The way the tutor helped me understand it, I understood to like its fullest, and I reviewed my notes, and I knew exactly what was happening with the equations and the formulas.*

Oscar actively sought assistance from tutoring centers and his professor to overcome the challenges he encountered in passing the Learning Targets he needed to retest. In the context of specifications grading, where students are required to reattempt assignments until they successfully meet the Learning Targets, it is reasonable to infer that such courses create a more compelling incentive for students to utilize campus resources. This is particularly true when compared to traditional grading systems which typically lack incentives for students to seek additional help after already having failed an assignment. Retesting on missed Learning Targets, on the other hand, potentially gave Oscar an incentive to have a growth mindset toward his ability to learn mathematics and continue learning the course content after he did not pass the first time, which led him to appreciate the value of tutoring services on campus. Oscar claimed, "I have all these resources around me literally at the learning center coming out of tutoring for a test, and it looks like I'm having success with it."

Case Comparison

Having the opportunity to resubmit his work when he did not pass it on the first attempt seemed to help Oscar persist in retesting until he passed a Learning Target. This differed from Carlos's experiences, as he detailed how his course's rapid pace, combined with a lack of resubmission opportunities, may have contributed to his sense of frustration and overall low perception of his own mathematical abilities. Oscar's experience underscores the importance of creating a learning environment that not only encourages students to seek support but also recognizes the value of persistence and continued learning. Specifications grading, with its retesting approach, played a pivotal role in fostering this perspective and promoting the utilization of available resources. Most importantly, these opportunities can foster students' growth mindset, persistence in learning mathematics, and, therefore, a stronger sense of mathematical competence and performance.

Carlos's and Oscar's Perceptions of Their Interest in Doing Mathematics

Carlos and Oscar were asked survey questions intended to measure their interest in mathematics: "I am interested in learning more about math," "I enjoy learning math," and the negatively worded survey item "I wish I didn't have to take math." Considering the radar charts in Figure 2 and Figure 3, we notice that Oscar yielded a large boost in this subconstruct as opposed to Carlos. This finding was further explored in the interviews.

Carlos

When asked about his experience in his traditionally-graded Calculus I course, Carlos shared how he felt his course seemed to adopt a rapid pace at the expense of student understanding:

> *I definitely didn't like how things just happened back-to-back... I go on a day, and we're being taught something. And then the next day I go, and we're being taught something new. So, there's never enough time to really get to understand the material in class.*

When further probed about whether this impacted his interest in mathematics, he replied by saying "I wouldn't say I enjoy it any more than I used to… Because of how much of it [mathematics] I'm being shown without it really being connected to anything. It's just math on top of more math." Due to Carlos's experience with hastily presented mathematics topics, he may have failed to see any relevance of mathematics to himself, which might have left him with an unchanged interest in mathematics.

To further identify the educational supports Carlos was hinting at, we asked him what he wished his traditionally-graded course would have been like. He responded,

> *Actually, having time [in class] to go over the things we did last, like the day before, or the last class. Somewhere we can also work in groups, and we can work alone as well. But keeping it related to what we already did and not something ahead … this would definitely make it more bearable.*

In other words, Carlos wished his traditionally-graded Calculus I course would have emphasized teaching practices geared toward meaningful learning opportunities that are more in tune with the learners' mathematical development and not merely a prescribed curriculum within an accelerated environment. Given that the specifications-graded Calculus I course involved the judicious placement of Learning Targets into its curriculum, including the instructional time that each target should receive, one can only speculate about the potential positive impact on Carlos had he been in a class using this approach.

Oscar

Oscar expressed a higher interest in mathematics during his interview. When asked whether he felt his interest changed throughout his specifications grading Calculus course, he claimed:

> *Yeah! Because if you start to see that you have success, then you're like – Hey, wait a minute, I've tested this. I can pass the following class. Let me try it out. Let me see if I can get through it. – like Calculus II and so on. And you start to challenge yourself with higher degrees of math and if you pass that one, then you move on you're like – Hey, let me see how far I can go. – So yeah, definitely!*

We can see the relationship theorized by Cribbs et al. (2015) in that a learner's interest in mathematics is influenced by their perceived mathematics competence and performance. It should be no surprise, then, that Oscar's perceived positive competence and performance in mathematics coincided with this increase in interest. Furthermore, we argue Oscar began to adopt a growth mindset when it came to his own mathematical abilities by recognizing that if he was able to be successful once, he could be successful again, regardless of the challenge.

Indeed, when asked about what factor(s) he attributed to his increase in interest, he expressed a key change in his originally fixed mindset about mathematics:

> *At one point, I would say - you know what? some people are gifted in Calculus and some people are not, and I am not, and I guess it's not reachable for me - But, you know, if you do it once, if things go right once, you know for sure you can do it again!*

Additionally, when asked about what made him change his mindset about mathematics, Oscar attributed this to his reassessment opportunities, a key characteristic of specifications grading:

> *When it comes to homework and tests, he [the instructor] wants you to follow every step exactly just perfect, and if you miss out on an equal sign or put the equal sign outside of the equation, or something along the lines of that, he will count it wrong. However, he doesn't add more [questions] like previous homework systems I've used. He doesn't give you like 15 more questions…Instead you can re-test … I love to retest, love it.*

Because of this ability to be re-assessed, it did not matter to Oscar that his instructor was strict on how he wanted students to demonstrate mastery in mathematics. On the contrary, we infer that the re-assessments encouraged Oscar to persevere in his studies, and this made him reflect on his overall purpose in the course: "Yeah, it [course design] can be a double-edged sword, but you know what? You also need to ask yourself - *do you actually want to learn it?*"

Case Comparison

It seems Carlos's experience in his traditionally-graded Calculus I course had a neutral impact on his interest in mathematics, as it remained unchanged. Even though a specification grading course would not have guaranteed Carlos a slower pace, one may infer that being in a course where students are provided with well-defined benchmarks, such as its Learning Targets, could have better aligned with what Carlos wanted from a Calculus course and impacted his interest in mathematics, positively. Oscar, alternatively, did yield a higher interest in mathematics throughout his specifications grading Calculus I course, and, according to him, this was attributed to his ability to demonstrate a strong competence and performance in mathematics due to his reassessments. This led to Oscar developing a growth mindset towards mathematics with respect to his mathematical abilities, which impacted his interest on future coursework.

Carlos's and Oscar's Perceptions of Their Recognition as Doers of Mathematics

Another subconstruct of mathematics identity is the learners' perceived recognition as doers of mathematics. This was measured with the survey items: "My parents/relatives/friends see me as a math person" and "My current math instructor sees me as a math person," respectively. The radar chart in Figure 3 demonstrates Carlos's recognition as a math person remains unchanged going from the pre-survey to the post-survey, whereas Oscar's recognition score increased by approximately two points. In the interviews, we further investigated their perceptions of whether their family, friends, and mathematics instructors recognized them as a "math person".

Carlos

When asked if friends or family tend to think of him as a math person, Carlos expressed frustration that his family and friends "definitely" perceived him as a math person: "It's frustrating because… I know that I'm *not* that much [of a math person]. But unfortunately, they keep this illusion, and I'm forced to be pushed down this path that they think I am on, but I'm not." We infer that Carlos not only did not perceive himself as a math person, given his frustration for being thought of as one, but he also expressed a sense of helplessness in not being able to meet his family's and friends' expectations. When probed to elaborate, Carlos responded:

> *Because I am ashamed. I keep being expected to do something that I'm not quite ready or capable of. And it just doesn't help with trying to understand the [mathematics] subject and trying to get better when you're being held at a standard that you're not quite ready to face.*

When asked if his current instructor saw him as a math person, Carlos said, "No more than anyone else." When asked whether previous mathematics instructors had even seen him as a math person, Carlos responded differently:

> *Probably somebody did back then, yeah. I remember that the parents would go to the class to talk to the teachers, back in like middle school and high school. I remember that teachers would say how well I was doing. That's what gave me the impression that they thought I was great at it [mathematics], I excelled at it [mathematics] … but things were a lot easier. I didn't have to worry about it as much. So, I'd like to get higher grades, but now, I am expecting the same when I'm struggling more. So, it's not quite the same anymore.*

We can see Carlos expressed a sense of helplessness in not being able to meet the expectations of others regarding his mathematical skills, hinting towards a fixed belief in his abilities. Carlos also recalls previous instances where teachers praised his mathematical abilities, but he attributes this to the ease of the content at the time rather than his own capabilities. This could suggest that he views his mathematical competence as contingent on external circumstances, such as level of rigor, rather than his own potential for growth and improvement, characteristic of a fixed mindset.

Oscar

When asked whether his friends and family saw him as a math person, Oscar claimed:

> *"Yeah, I think they do because of what field I'm majoring in." Contrary to Carlos, however, Oscar hinted toward a sense of pride when being thought of as the math person in his circle of friends: "My friend is the doctor of the group, and then we have my other friend, the accountant of the group, and then we have the engineer of the group, that would be me, the math person, and that is a nice group of friends to have." A similar sentiment was expressed when asked whether his past instructors ever saw him as a math person: "I don't know. I'm thinking back to my instructors. I think only two of them saw me as a math person, but they saw me more like an engineer or maybe a robotics person." This also included his mathematics instructor: "My current Calculus professor kind of tells everyone - oh yeah, you guys, you guys are future engineers - and stuff like that. I find it cliché. But at the same time, I don't because I think he does kind of have some sense of truth in his sentences when he does mention that to us. I do believe him."*

Contrary to Carlos, Oscar's pride in being seen as a "math person" by his friends, family, and instructors indicate a belief in his own abilities and potential for growth in mathematics. Additionally, he acknowledges the truth in his instructor's statements about being future engineers, indicating a willingness to accept and pursue opportunities for growth and development in his chosen field.

Case Comparison

From the surveys and interviews, it is difficult to tell if the traditionally-graded Calculus course attributed to Carlos's lack of increase in his perceived recognition as a math person. What we can posit, however, is that Carlos's negative experience in his traditionally-graded Calculus I course could have contributed to his fixed mindset where he sees his abilities as unequalled with external expectations and, therefore, his imposter feeling. Because of how he perceived his mathematical competence and performance, it is possible he felt frustrated and even ashamed for being thought of as a math person by his family and friends. This aligns with Cribbs et al.'s (2015) theory that one's recognition as a math person stems from one's own perception of mathematical competence and performance. Therefore, one can only conjecture if such identity dissonance would be alleviated if Carlos were in a specification grading Calculus course. Similarly, we cannot confidently assert that Oscar's experience in his specifications grading Calculus course attributed to an increase in recognition as a math person. What his responses may hint to, however, is that being in a specification grading Calculus course may have increased Oscar's sense of competence and performance, which thereby contributes to his comfortability with being recognized as a mathematics person.

Carlos's and Oscar's Perceptions of Their Own Mathematics Identity

According to Stevens et al. (2020), one's perceived mathematics identity is informed by one's self-perceptions, beliefs, attitudes, and emotions about mathematics, especially how one sees themselves as a mathematics learner and doer. Carlos's and Oscar's mathematics identity was measured with the survey item "I see myself as a math person". The radar chart in Figure 3 demonstrates Carlos's self-perception as a math person increased by one point between the pre-survey and post-survey, whereas Oscar's self-perception as a math person demonstrated an increase of two points. Because of the complexity that lies with any identity construct, we also asked both Carlos and Oscar during their interviews if they saw themselves as a math person. This response was cross-referenced when we later asked them to rate themselves as 1) mathematicians, 2) scientists, and 3) STEM professionals, respectively, using a Venn diagram activity (see Figure 4) on a 1 – 5 scale. In all, this allowed us to further explore their conceptions about what it meant to be a "math person" and whether they felt they were aligned, or not, with this identity marker.

Carlos

When asked if he felt identified as a math person, Carlos responded: "No. [There is] just a lot to understand and to remember. I mean, I'm having trouble there [traditionally-graded Calculus I course] now, and thus I don't think I would be able to call myself much of a math person." Furthermore, when asked whether he felt anyone could be a math person, if they so desired, he replied by saying: "I wouldn't say so. I'd say if they felt the need or the requirement, then perhaps, but I don't know about it being for anyone who can't just do it." We infer that Carlos's understanding of a math person is someone successful in fully understanding and remembering the numerous mathematics concepts that exist. In other words, if one fails to understand and recall everything there is to know about mathematics, then one should not identify themselves as a math person. Additionally, Carlos hinted towards the idea that mathematics is an innate talent possessed by only a select few given that some people "can't just do it," which is strong evidence of having a fixed mindset toward the ability to do mathematics.

Several interview questions afterward, using the Venn diagram activity, Carlos rated himself a 2 for mathematician, for which he explained:

> *I'm not really as prominent in math enough to say to myself that I would align myself with someone who would have studied that [math] or would understand that [math]. But also, I am not completely isolated from it [math] or separated from it [math]. That's why it's not quite in the middle but it's leaning a little further away.*

Because of his engineering major, Carlos felt somewhat aligned with the identity of a mathematician. However, once again, he expressed sentiments of having a low ability in mathematics with not being a mathematics person.

Carlos also rated himself as a 3 for both scientist and STEM professional in the Venn diagram activity, and he justified it by saying:

> *Because I feel like I understand the connection between my major and being a scientist or STEM professional … I can feel how it is connected. But with math, I haven't seen enough of it, yet, to see how what I'm doing in math is aligned with the STEM professional and such.*

Because Carlos can see the connections between his engineering major and a scientist or STEM professional, he feels more identified with both identity markers. This could imply that since Carlos does not see connections between what he sees in his Calculus I class and his engineering classwork, he does not feel as strongly identified with it.

When asked whether he would have rated himself differently if he would have been asked to do this same activity during the first week of class, Carlos claimed:

> *They would have been different. What's the word? Naïve. I would feel more optimistic [about his Calculus I experience] because I haven't done it yet. I haven't been there to actually have to do this stuff. It'd be a little higher probably…I think I would have gone for three. But science, I would probably would have gone for a two as I wouldn't have seen a connection there, yet. Same for STEM.*

Because of Carlos' testimony, we may infer that being in a class that assesses your understanding without affording opportunities for resubmission of your work can reinforce the belief that being a "math person" is an all-or-nothing proposition. In such an environment, students might develop the perception that either they naturally comprehend mathematical concepts, or they do not, with little room for growth or improvement. This rigid view, in return, can lead individuals to believe that their mathematical abilities are predetermined and unchangeable (i.e., a fixed mindset). In contrast, an educational approach that allows for reevaluation and resubmission of work, as exemplified in specifications grading, can convey the idea that mathematical competence can be developed and improved over time through effort, practice, and learning from mistakes (i.e., a growth mindset). This can be particularly motivating for students who might have initially struggled with mathematics but are determined to enhance their skills and understanding.

Oscar

When asked whether he identified as a math person or not, Oscar expressed a similar sentiment to that of Carlos:

> *I would say no, not to an extent because I don't know everything about math, yet. I'm still in Calculus I going to Calculus II and so like I can't really call myself a math person if I don't know everything. Once you master the whole field, then you can say - Yes, I am a math person.*

Like Carlos, Oscar's concept of a math person involves having a comprehensive understanding of the subject, essentially reaching the point where one knows "everything" there is to know within the field. However, Oscar's perspective is marked by a more optimistic tone, evident in his choice of language. For instance, the inclusion of the word "yet" may hint toward a growth mindset, as it suggests that Oscar views the goal of becoming a math person as an achievable one, a sentiment not as apparent in Carlos's response. Additionally, Oscar's confidence in implying that he will be successful in his Calculus I course and, therefore, enroll in Calculus II reinforces this optimistic outlook. This growth mindset was further evident when asked if anyone could be a math person:

> *Yes! Anyone has the, I don't want to say the same type of intelligence, but everybody does have that same grit to be able to learn and grow with this concept of math. Anyone, and I mean anyone! If you have a low IQ or high IQ, anyone can do it. I'm sure about it because it all has to come down to the mentality that you have towards this type of subject or any subject for that matter because anybody can switch on a dime and have the mentality and*

dedication to say – You know what? I am going to be successful in math! – Because that happened to me.

Undoubtedly, Oscar's response to this question is characterized by an optimistic and inclusive perspective on success in mathematics. The central argument posits that success in mathematics is not contingent on a specific type of intelligence but is achievable by anyone, regardless of whether they have a "low IQ or high IQ." The assertion of "everyone having the same grit" to learn and grow in mathematics underscores the belief that it is not an inherent trait but rather a matter of determination and effort, underscoring a strong growth mindset. Oscar's personal experience further serves as a concrete example to support this stance, indicating that a change in mentality and dedication can lead to success.

When asked to rate himself as a mathematician using the Venn Diagram (see Figure 4), he rated himself as a 2 because: "I don't want to say I am a full mathematician because, you know, I still have that tendency to, like, not liking math. But I'm liking it. I am liking it a little bit right now because I'm passing it." Oscar demonstrated another dimension to his construct of a math person. Not only can anyone be a math person, if they wish, but performing well in mathematics seems to have increased his interest in mathematics and, therefore, his overall identity as a math person. He also rated himself a 3 for both scientist and STEM professional as he justified it by saying:

I think that these have to do with science, technology, robotics, and obviously math and engineering, and so that's why, on a good day I'd say four, but honestly, I've been away from face-to-face classes on engineering and stuff like that, and so that's why I'm being humble and putting myself at a three.

However, when asked about whether he would have rated himself differently if he had been asked to do this same activity during the first week of class, Oscar claimed: "If you would have told me for a mathematician, if there was an option zero, I'd put zero. Yeah, for a scientist I would've put myself at a two and not a three. STEM I would put myself as a two. Maybe a three as well." He justified this by saying:

You know, some time ago, I was at a low point, and I was like - you know what, I don't know math anymore, I don't know what's what anymore. Demotivated. I don't want to do it anymore, and it was just very demotivating because I had failed Calculus twice. But now, I can put myself higher, now. I think it's because you get these opportunities to show understanding. And you master that, and that motivates you to move forward.

Taking this entire exchange into consideration, it is reasonable to infer that Oscar's participation in a specifications-graded Calculus I course might have contributed to the development of his growth mindset that sees mathematics mastery as something obtainable. At one point, for example, Oscar's mindset shifted into one that considers that anyone has the same "grit" to be successful in mathematics. Oscar also attributed this to the multiple opportunities for reassessment that his specifications-graded Calculus I course offered and how this positively influenced his motivation to move forward and, thus, his growth mindset. This response underscores the significant influence that pedagogical approaches such as specifications grading can have on students' perceptions and emotions related to mathematics. It also highlights the potential to reignite students' interest and motivation in the subject, even after previous challenges or setbacks.

Case Comparison

At first glance, it seems that Carlos and Oscar share some similarities in their perceptions of being a math person. Both seem to associate being a math person with having a comprehensive understanding of mathematics, implying that "knowing everything" about mathematics is a fundamental aspect of this identity. Both students also express a sense of doubt about considering themselves math people given that they have not reached that level of mastery. However, a careful examination of their interview responses alluded to key differences in their interpretations of what it means to be a math person. The primary difference between their perspectives lies in their optimism and fixed or growth mindset towards this identity. Carlos, on the one hand, exhibits signs of a fixed mindset, expressing skepticism about the attainability of this status. He implies that not everyone can become a math person, and he hints at the idea that mathematical talent may be an innate quality possessed by only a select few. In contrast, Oscar's perspective is marked by a more optimistic tone that is evidence of a growth mindset. While he also defines being a math person as having a profound understanding of mathematics, he believes that this goal is attainable. He emphasizes the importance of one's mentality and dedication and expresses a strong belief in the potential for anyone, regardless of their IQ or prior performance, to become successful in mathematics. Furthermore, Oscar's experience with a specifications-graded course appears to have played a significant role in shaping his more optimistic perspective and growth mindset. The opportunities for reevaluation and the chance to demonstrate understanding within specifications grading seem to have positively influenced his motivation and confidence, emphasizing the influence this approach could have on students' overall mathematics identity development.

CONCLUSION

Since Calculus courses often act as gatekeepers for undergraduate students pursuing STEM degrees (Norton et al., 2017; Pyzdrowski et al., 2013; Suresh, 2006), particularly those from disadvantaged groups (Convertino et al., 2022), there is a need for research on innovative pedagogies in Calculus courses that can mitigate this gatekeeper effect. Our case study contributes to this need by investigating the experiences of a Hispanic student in a traditionally-graded Calculus I course and a Hispanic student in a course with specifications grading. The results of this case study highlight how specifications grading, when applied in a high-stakes foundational course like Calculus I, may disrupt the rigid, high-pressure structures that often undermine student confidence and identity formation, particularly for historically marginalized populations. By studying Calculus I in particular, we focus on a critical course where retention decisions are often made, making the implications of assessment structure especially consequential for equity in STEM education.

This study explored the impact of specifications grading on Oscar's mathematics identity compared to Carlos's experience in a traditionally-graded Calculus I course. Evidence suggests that due to Oscar's ability to resubmit his work in his specifications grading Calculus I course, he persevered in retaking exams until he succeeded in mastering a particular learning target. This differed significantly from his previous experience in a traditionally-graded Calculus course where failure to demonstrate mastery at a first attempt resulted in his self-demoralization. It seems his experience in his specifications grading course may have also had an impact on his mindset toward learning, in general, as he expressed a shift from thinking about mathematics as an innate talent to something that is “reachable.” This may have also positively influenced his own perception of his mathematical understanding and abilities which, as exemplified by Cribbs et al. (2015) theorized model, may have also impacted his interest in mathematics and his perceived recognition as a math person. Indeed, Oscar expressed an increase in his interest in mathematics, claiming that because of this success in his specifications grading Calculus I course, he was looking forward to his Calculus II course. Results from Oscar's pre- and post-survey also yielded an increase in his perceived recognition as a math person. Although we cannot confidently conclude this increase was due to this specification grading course solely from the interview data, Cribbs et al. (2015) model does yield the possibility that this was due to his increased perception in his own mathematical competence and performance.

In contrast to Oscar, Carlos described the difficulties in keeping up with the rapid pace and the lack of opportunities to resubmit assignments in his traditionally-graded Calculus I course. Furthermore, it seems this experience cemented his idea that mathematical proficiency is not accessible to everyone, that is, a fixed mindset, as he described himself as someone who used to excel in mathematics but, due to his perceived lack of understanding, is no longer capable of doing so. While it cannot be assumed a specification grading course would have necessarily offered a slower pace to Carlos, it is plausible to assume that being in a course where students are not required to exhibit mastery at their first attempt may have been more in line with Carlos's preferences for a Calculus course. This may have impacted Carlos's perception of his mathematical comprehension and abilities and may have even sparked a higher interest in the subject. Carlos also expressed being recognized as a mathematics person by his friends and family, mostly because of his classification as an engineering major, and it seems this remained unchanged judging by the pre- and post-survey. Carlos was ashamed of such a label as he did not feel identified with this construct. This hinted toward the idea that Carlos did not see himself as a mathematics person, and the identity dissonance this created brought distress to his psyche. One can only conjecture if such identity dissonance would be alleviated if he were in a specification grading Calculus course where he would be given the educational supports he hinted at.

When discussing the mathematics identity construct, both Oscar and Carlos agreed in that they both did not fully identify as "math people." Upon a careful examination of their interview responses, however, it became apparent that Oscar and Carlos held different perspectives on what it means to be a "math person." Carlos equated being a math person with the ability to perform well in mathematics, which aligns with Cribbs et al.'s (2015) model linking one's self-perception of mathematical abilities with the development of their mathematics identity. However, Carlos exhibited a fixed mindset by stating that understanding and performing well with mathematics does not guarantee success, and due to his experiences, he did not identify as a math person. Contrastingly, Oscar's definition of a math person emphasized a comprehensive understanding of mathematics, with a focus on completion, and he did not feel he had reached that level, yet. Unlike Carlos, Oscar seemed to believe becoming a math person was achievable for anyone who desires it, which exhibited his growth mindset.

These findings led us to argue that specifications grading could foster students' growth mindset (Dweck, 2006) by offering multiple opportunities for mastery and encouraging students to seek help, such as at tutoring centers. Other researchers (e.g., Sun, 2018) have claimed that assessment practices related to giving verbal praise, written feedback, and opportunities for students to re-attempt work and seek help could promote students' growth mindset. Our study extends this literature by documenting how specifications grading, by which these assessment practices may be enacted, can help shape students' growth mindset and ultimately their mathematics identity. The relationships among the theoretical constructs of students' growth mindset, sense of competence and performance in doing mathematics, recognition as a math person, and interest in doing mathematics can provide a potentially fruitful direction for additional research to explore. Researchers could quantitatively test causal relationships between courses' implementation of specifications grading and improvements in students' growth mindset and mathematics identity. This could involve performing statistical analyses of measures of students' growth mindset and mathematics identity development in specifications grading courses, compared to such development of students in traditionally-graded courses. Researchers could also examine the effects of specifications grading on student achievement and affect (e.g., attitudes, confidence, interest) in mathematics courses other than Calculus, as well as in disciplines besides mathematics.

We acknowledge that some limitations to our methodology exist, which could have impacted the interpretation of our findings. Firstly, mathematics identity is a complex construct in the mind of an individual, which researchers do not have direct access to. We could only make inferences about students' mathematics identities based on their verbal expressions of their perceptions of their competence, performance, interest, and recognition in doing mathematics. Another limitation is that we have only two participants that served as cases. Given this small sample size, we make no claims about the generalization of these findings to all Calculus students. Our findings instead have theoretical generalizability; the theorized relationships we identified among the specifications grading pedagogy, students' growth mindsets, and students' mathematics identities could still hold for other specifications grading Calculus courses. Lastly, there could be alternative confounding factors (e.g., students' backgrounds, time spent studying, learning environments), that might have affected the results of this study.

Further research is needed to explore how mathematics identity, growth mindset, and specifications grading further interact in shaping the experiences of Hispanic students in STEM fields. Most importantly, it is crucial that we continue to transform the way we teach Calculus, especially given its role as a gatekeeper for many students seeking STEM degrees. Indeed, there is an abundance of nationwide appeals for the transformation of Calculus, as students' poor performance and low confidence in Calculus often leads to students abandoning STEM degree programs (Ellis et al., 2016). Unfortunately, approximately 40% of students who initially enter universities with aspirations of pursuing STEM degrees ultimately graduate with one (President's Council of Advisors on Science and Technology, 2012; Pedraza & Chen, 2022). Even more troubling is the fact that Hispanic students experience failure rates in Calculus that are over 50% higher than those of White students (Champion & Mesa, 2018). Given these systemic inequities, academic stakeholders and Calculus instructors have an ethical obligation to reform Calculus courses with innovative pedagogies that can increase student success and retention by fortifying students' mathematics identities. Furthermore, there is a need for research on the effectiveness of these pedagogies in impacting students' mathematics identities. Our case study contributes to this need for research by investigating how students' mathematical identity development is influenced by specifications-graded versus traditionally-graded Calculus I courses, offering insights into the possible broader implications that can transform Calculus I courses.

Overall, implementing innovative pedagogies, such as specifications grading, has the potential to foster students' mathematics identity development. Specifications grading realizes this by providing students with multiple opportunities to meet their mathematics learning objectives, thereby fostering the potential for students to develop growth mindsets and more robust mathematics identities. We encourage mathematics instructors to implement specifications grading or other forms of alternative grading in their assessment of student learning outcomes. Instructors can organize their course content into a list of learning targets, which they can assess students on. Instructors can then give students feedback on their failed attempts and give additional support or tutoring before the students reassess to pass the learning target. Our findings illustrate the benefits of specifications grading on students' growth mindsets and sense of competence in doing mathematics, for if students do not pass initially, they can pass the learning target on a subsequent reassessment or revision of prior work. This keeps students motivated to continue learning the content until they succeed in passing the assessment.

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