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Exploring the role of students' views of creativity on feeling creative

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ABSTRACT

Creativity is crucial for doing mathematics, yet many United States students may not have opportunities to experience it in their courses. Moreover, the literature base on views of mathematical creativity lacks the student perspective. To explore the connections between views of and feeling creative, we examine differences in views of creativity between students who felt creative and did not feel creative in an interventional Calculus I course. We conducted semi-structured interviews with 37 undergraduate students taking a creativity-based Calculus I course across the United States, for their views on creativity and whether they felt creative in the course. Approximately three quarters felt creative ($n = 27$), while one quarter of students ($n = 10$) did not. Using qualitative coding, we found that students who did not feel creative were more likely to view creativity as including *understanding* and *applications*. In contrast, students who felt creative were more likely to view creativity as *originality* and *actions and attitudes* they could take. We recommend instructors take actions focusing on *originality* and *actions and attitudes* to help foster students' creativity. Finally, we discuss how all ten students who did not feel creative came from groups that have been historically marginalized in mathematics.

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1. Introduction

Creativity is an important part of doing mathematics for students (Leikin, 2009; Mann, 2006; Moore-Russo & Demler, 2018; Silver, 1997). From a pedagogical viewpoint, mathematicians see creativity as essential for success in mathematics (Borwein et al., 2014) and for approaching new problems. From a societal perspective, Science, Technology, Engineering, & Mathematics (STEM) workforces list creativity as a sought-after skill in applicants, according to reports by IBM (2010) and the World Economic Forum (Schöning & Witcomb, 2017). As technology shapes available careers around the world and people's

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livelihoods, it is crucial that we actively help students develop creativity in their STEM courses.

Calculus is an appropriate place to foster and study creativity among tertiary-level mathematics courses for the following reasons. First, calculus is a required course for most STEM majors (Ellis et al., 2016). Second, calculus reaches a larger student audience than proof-based courses, where existing research on creativity has focused. Lastly, calculus sadly acts as a gatekeeper in STEM (Ellis et al., 2016). Students leave STEM majors over poor experiences, oftentimes due to 'unresponsive teaching strategies' (Johnson et al., 2015, p. 722), with ramifications for the global workforce as well as their individual futures. Ryals and Keene (2017) interviewed 14 students about success in Calculus and queried: 'could the development of CMR [Creative Mathematics Reasoning] in Calculus I lead to greater success in Calculus II?' (p. 877). There is a need then to examine mathematical creativity and its potential benefits for Calculus students.

In this study, we explore the following research question: What are the differences in students' views of creativity, between calculus students who feel creative compared to students who do not feel creative? In calculus courses explicitly encouraged to foster mathematical creativity, we examine what students who felt creative and students who did not report as their reasons for feeling so. We focus on the views of students who did feel creative as success cases of our intervention, while also acknowledging the views of the students who did not feel creative. We provide cases of how some students talked about creativity to illustrate why these views may be conducive to feeling creative. The purpose of this work is to explore the role one's views of creativity play in feeling creative, to better understand how tertiary mathematics instructors may support students' development of mathematical creativity in the classroom.

2. Background literature

In our forthcoming article (Cilli-Turner et al., 2021), our group detailed many of the dominant views of creativity and argued for the inclusion of more student views of mathematical creativity. Our reasoning was that 'if we limit defining creativity to the experiences of the experts, then we risk excluding people who do not identify with those experts' (p. 2). With this acknowledgment, we will cite definitions of mathematical creativity grounded in student and non-mathematician perspectives.

Previous research has traditionally considered originality as a property of mathematical creativity. Indeed, according to Runco and Jaeger (2012) in the psychology literature, a 'standard' definition of creativity must include novelty, which is synonymous with originality. Silver (1997) and Leikin (2009) conducted empirical studies in which they discussed other components of creativity, however, such as fluency, flexibility and elaboration (Torrance, 1974).

Mann (2018) collected student definitions of mathematical originality. Three of the six students interviewed had relative definitions of originality, that work that is new to the person can be seen as original. Five of the six also expressed a view of originality, as compared to their peers, but only acknowledged absolute creativity with regard to the whole field of mathematics. Mann also asked students to compare their definitions to Leikin's (2009) definition of originality: the 'use of an insight-based or unconventional solution' (p. 136). Leikin's definition was modified from the Torrance (1974) definition of originality, one of the more common psychological traits included in definitions of creativity. Moore-Russo and Demler (2018) asked 13 in-service teachers about their definition of creativity and found results similar to Mann, with 12 of the 13 teachers identifying novelty as an aspect of creativity.

Mann (2018) also acknowledged that the same concepts of originality from students aligned with the 4P's that Rhodes (1961) conjectured. The 4P's are (1) characteristics and attitudes of Persons that are creative, (2) creative Products, (3) creative Processes, and (4) the creative Press, which is the social environment properties that are conducive to creativity. Since our research questions and ideas align with asking the student about their lived experiences (see Section 2), we will focus on creative Persons. Rhodes defined the person-view of creativity as 'information about personality, intellect, temperament, physique, traits, habits, attitudes, self-concept, value systems, defense mechanisms, and behavior' (p. 307). This view of creativity has been included in many different contexts, including the fostering of 'person' in the classroom through the 'press'. If creativity is fostered in the classroom, students can develop their own communication skills, new experiences through exploration, and cognitive flexibility (Luria et al., 2017).

While much research exists on creativity in K-12 settings (Mann, 2006) with fewer studies at the tertiary level (e.g. El Turkey et al., 2018; Karakok et al., 2020; Savić et al., 2017; Leikin, 2009), many of these studies have not explored students' views of creativity and the impacts of these views on whether students feel creative or not in the classroom, specifically in the Calculus context. We attempt to fill this gap in the literature by the aforementioned guiding research question: What are the differences in views of creativity between calculus students who feel creative compared to students who do not feel creative?

3. Theoretical perspective

In this study, we take a phenomenological approach: People's perceptions of their experiences reflect their lived realities (Abakpa et al., 2017; van Manen, 1990) and so perceptions are a useful construct to study. People's perceptions of past events influence their orientation towards current and future events; similarly, students carry their perceptions of past mathematical learning experiences with them into future situations. For this reason, we do not claim whether students are or are not creative by any outside measure; rather, we report students' self-perceptions of feeling creative as the most salient here.

Our conceptual view of creativity is based on the following three assumptions. First, we operate under the assumption that every student can be mathematically creative. In keeping with the phenomenological approach, we view being and feeling creative as equivalent under our lens and as such is the student's internal judgement. This is inspired by asset-based approaches in mathematics education (e.g. Adiredja & Louie, 2020) and a positivist approach in psychological creativity research that 'creative potential exists within the individual' (Corazza & Glăveanu, 2020, p. 82). This is in contrast with dominant narratives that only certain people are creative (creativity as 'genius') which permeates public discourse let alone mathematics spaces (Silver, 1997). Second, we believe there is no one way to be creative, or even *feel* creative, so we intentionally use the word 'foster' to emphasize that creativity comes from within students. Third, we do not fault students who do not feel creative as deficient. There are many reasons why students may not feel creative in mathematics. To not feel creative in a mathematics classroom is a rational response, given the rigid educational environment around mathematics, students are in. Rather, by understanding how students view mathematical creativity, we can better identify what actions instructors should take and emphasize in the classroom to foster creativity.

4. Methods

4.1. Participants

This paper is an extension of an existing study about students' views of creativity (Cilli-Turner et al., 2021), drawing from a two-year project about fostering undergraduate students' creativity (e.g. El Turkey et al., 2020; Tang et al., 2020). Specifically, we focus on a 'creativity-based' Calculus I course across different United States institutions, which we did not in our previous work, and we go in depth on feeling creative versus not feeling creative in the course intersecting with their views of mathematical creativity. The participants were 37 undergraduate students enrolled in a Calculus I course: 12 in cohort 1 (Spring 2019) and 25 in cohort 2 (Spring 2020).

We categorized students' self-identified gender and racial identities as provided through both a survey taken at the end of the semester and as questions at the end of an interview. By gender, there were 26 women and 11 men. We use the term 'people of color' (POC) to refer to students who identified other than only White or Caucasian (Debby Ellis Writing Center, n.d.). This included reported races and ethnicities such as African-American, African, Asian-American, Eastern Indian, Hispanic, Mexican, and South American, as well as identifying as more than one race. There were 22 POC and 15 White students.

4.2. Setting

Calculus I, as taught at the tertiary level in the United States, often includes limits, derivatives, optimization, and basic integrals. As an intervention, creativity-based classrooms were taught by faculty who self-selected to participate in a grant-funded project for fostering creativity. Faculty engaged in weekly online professional development, where they designed creativity-based tasks (El Turkey et al., 2020) and then facilitated them in the classroom along with a Creativity-in-Progress Reflection tool on Problem Solving (Karakok et al., 2020). No additional pedagogical techniques were required of faculty teaching in creativity-based classrooms.

4.3. Data collection

Semi-structured interviews were conducted with each participant at the end of the semester in which they took the calculus course. Each interview lasted approximately 60–90 min long and was done using video-conferencing software Skype or Zoom. The interview included questions about students' experience in the course, questions about classroom tasks, and their views of mathematical creativity. Results reported in this paper largely come from two interview questions: 'What is your definition of mathematical creativity?' and 'Did you feel creative in your Calculus I course?' Interviews here are one of a larger set of data sources (video recordings of professional development, interviews with instructors, surveys, etc.) that will not be reported on here. Finally, students chose their own pseudonyms, which we use throughout the paper.

4.4. Data analysis

Interviews were audio-recorded and transcribed. We qualitatively coded the transcripts for students' views of creativity using the following bottom-up coding process (Strauss & Corbin, 1990). In our first phase of coding, we used in vivo coding (Saldaña, 2015) to analyze data from cohort 1 students, to highlight students' own words in their voicing of their views. We gathered and collapsed all the in vivo codes into eight themes. In our second phase of coding, we applied these eight themes to then code cohort 2 students' transcripts. Three authors coded and engaged in a norming process: All three authors coded the same four students in cohort 2. After discussion, two of three authors coded another six students and one author coded the remaining students. Additionally, two authors coded the reasons students reported for not feeling creative. Rather than traditional inter-rater reliability, we 'rel[ied] on intensive group discussion and simple group 'consensus' as an agreement goal' (Harry, Sturges, and Klingner, 2005, p. 6). Significant discussion, particularly when there was ambiguity, occurred and norming was completed. In the final round of coding, we collapsed our themes to six themes total, due to lack of conceptual separability and number of instances.

Students' views often had multiple themes, which were defined to be mutually exclusive. For example, a variety of themes can be seen in this quote from Clare (White woman) about what it means to her to be creative:

> So I think it kind of is similar to being *persistent [Attitudes & Actions]*, because the more so you're persistent, the better your ideas are going to be and the better you are, at least for me. If I keep going, there's way better chance I'm going to *find different ways to solve it [Different Ways]* that are more in tune with what I know and what *I'm comfortable with doing [Attitudes & Actions]*. And so I think just like working really hard and *finding those new ways [Originality]*, finding something that can really *help me understand [Understanding]* is what I see.

For this reason, counts of students who viewed creativity as including a certain theme are not mutually exclusive.

We also categorized students as to whether they saw themselves as creative, based on their answer to 'Did you feel creative in your Calculus 1 course?' This led to two groups: students who reported that they felt creative and students who reported not feeling creative. In keeping with the phenomenological approach, students were categorized into one of the two groups based on their answer to this question only, regardless of whether they reported conflicting feelings elsewhere in the interview. In the results section, we explicate the differences present in students' views of creativity based on this categorization of students into two groups: Feeling Creative (C) and Not Feeling Creative (NC).

5. Results

We first report the number of calculus students who felt creative (C) compared to students who did not feel creative (NC) and their demographics. Then, we compare the prevalence of themes found in C and NC students' views of creativity. Two themes – *Originality* and *Actions & Attitudes* – stand out as more prevalent across C students, so we provide student cases to show the strong connections to feeling creative. Lastly, we examine the reasons students reported for not feeling creative and identify links to themes of *Application*, *Outside Authority*, and *Understanding*. We emphasize that we do not argue that NC students

Table 1. Students' perceptions of creativity by gender and race.

	Gender		Race	
Students	Men	Women	POC[a]	White
Felt creative (C) ($n = 27$)	9	18	14	13
Did not feel creative (NC) ($n = 10$)	2	8	8	2
Total	11	26	22	15

[a]POC: people of color.

are in fact not creative; rather, they reported not feeling creative when directly asked in the interview and we seek to explore why they feel that way, in effort to support them.

5.1. Demographics of students who felt creative (C) versus did not feel creative (NC)

Of the $N = 37$ students, 27 students felt creative and 10 students did not feel creative. Table 1 shows the breakdown of these students by gender and race.

Of the students in the C group, two thirds were women: 18 women and 9 men. C students were evenly split by race, with 14 POC and 13 White students. However, of the 10 NC students, 8 were women (and 2 men) and 8 were POC (and 2 White) students. Since the two White NC students were women, all of the NC participants were from historically marginalized groups in the United States in mathematics. Furthermore, 6 of these 10 students said they were first-generation college students, defined as the first member of their family to attend college. We do not have data to support further claims regarding intersections of identity and feeling creative, but we provide possible explanations in Section 5.

5.2. Differences in themes in C and NC students' views of creativity

Students' views of creativity fell into six general themes: *Actions & Attitudes, Application, Different Ways, Originality, Outside Authority* and *Understanding*. Students who viewed creativity as *Actions & Attitudes* reported creativity as characteristics and habits they could enact, for example, confidence, feeling comfortable, play, willing to try, wondering, on my own. *Application* referred to creativity as applying some mathematics to other situations, whether mathematical, other disciplines, or real life. The theme of *Different Ways* represented when a student spoke of multiple approaches or techniques when solving a problem. *Originality* concerned creation of novel mathematics, in relation either to the student or the field. When a student spoke of creativity as going against an established Authority figure, such as a teacher or a textbook, it was coded as *Outside Authority*. Finally, *Understanding* was applied when a student referenced learning of concepts or material in the class. Detailed descriptions of these themes with examples are given in Cilli-Turner et al., (2021).

Across all $N = 37$ students here, *Different Ways* (84%), *Actions & Attitudes* (62%) and *Understanding* (62%) were the most prevalent themes in students' views of creativity, as seen in Table 2. Viewing creativity as *Application* was the least common (30%). However, comparing the two groups of C students ($N = 27$) and NC students' views ($N = 10$), the largest differences were in students viewing creativity as *Actions & Attitudes* and *Originality*. We found that 14 of the 27 (52%) C students viewed creativity as *Originality*, compared

Table 2. Themes in students' views of creativity versus perceptions of feeling creative.

	Themes					
Students	Actions and attitudes	Application	Different ways	Originality	Outside authority	Understanding
Felt creative (C) ($n = 27$)	21 (78%)	7 (26%)	24 (89%)	14 (52%)	11 (41%)	15 (56%)
Did not feel creative (NC) ($n = 10$)	2 (20%)	4 (40%)	7 (70%)	2 (20%)	2 (20%)	8 (80%)
Total students ($n = 37$)	23 (62%)	11 (30%)	31 (84%)	16 (43%)	13 (35%)	23 (62%)
Ratio C to NC	3.89	0.65	1.27	2.59	2.04	0.69

Note: We compared themes in how students who felt creative (C) and did not feel creative (NC) viewed creativity. For a given theme (in columns), the 'Ratio C to NC' is the percentage of C students divided by that of NC students who reported that view.

to only 2 of the 10 (20%) NC students. Similarly, 21 of 27 (78%) C students viewed creativity as *Actions & Attitudes*, compared to only 2 of 10 (20%) NC students. Among C students, 11 students included both *Originality* and *Actions & Attitudes* in their view of creativity, showing a high overlap. There were only 4 of the 27 C students who did not view creativity as neither *Originality* nor *Actions & Attitudes*.

Given the different numbers of C and NC students, for each theme, we computed a 'Felt Creative: Not Creative Ratio' by dividing the percentage of C by the percentage of NC students whose views of creativity included that theme. This ratio shows how likely a C student would include that view of creativity compared to an NC student. A ratio of 1 indicates a C and an NC student are equally likely to view creativity as including that theme. A ratio with a magnitude over 1 indicates a C student is more likely to view creativity as including that theme. A ratio with a magnitude between 0 and 1 indicates an NC student is more likely to include that theme in their view of creativity.

Originality and *Attitudes & Actions* showed the strongest differences: C students were 2.6 times as likely to include originality in their view of creativity and 3.9 times as likely to include actions and attitudes compared to NC students. *Outside Authority* was smaller, with C students being twice as likely to view creativity as having an element of going against an authoritative source than NC students. *Understanding* and *Application* had smaller shares among C students compared to NC students: C students were less likely to view creativity as including *Application* or *Understanding* (.65 and .69, respectively) compared to NC students.

In summary, the largest differences between the C and NC groups were in students viewing creativity as including *Originality* and *Actions & Attitudes*. We therefore explore these two ideas further, to better understand what role these two themes play in students feeling creative.

5.3. *Role of actions and attitudes and originality in feeling creative*

Delving into these two themes, we explore one idea from each of Actions & Attitudes and Originality that multiple students discussed. We do not claim all C students felt this way.

5.3.1. Actions & attitudes: comfort

Actions & Attitudes may be associated with feeling creative because when students view creativity as actions they can take or conditions that when met lead to being creative, creativity is now something in their own agency. We focus here on the importance of comfort, as many students reported feeling comfortable as a condition for creativity. 007 is an Asian woman majoring in biology and minoring in economics. She emphasized the role of patience and time in creativity:

> I think I'm more comfortable with spending a longer time, a longer amount of time on a problem than I might have in another math class where it's just like, solve it. Done. Where now I know there is still an added step or there's still something more I need to explain. And maybe patience is like a factor in that creativity because, you know, *creativity can come when you're just kind of like spacing out and you think, 'oh, there's nothing more.' But then I was like a little light bulb went off and that happened in this class.* So I think I got something out of that.

We see here the chain of effects through which a sense of comfort led to AHA-moments (Liljedahl, 2005) and feeling creative. To 007, other math classes are 'solve it. Done'. As a result of norms in her creativity-based class, 007 felt more comfortable spending a longer amount of time on a problem. Therefore, she felt she could be patient when working. This contrasts with how speed is often associated with and valued in school mathematics. By feeling comfortable in taking her time to think and releasing an expectation of finding an immediate answer, she experienced an AHA-moment.

The feeling of comfort was also commonly reported by students as important for doing problems that looked different from problems done in class. Aon is an African-American woman majoring in pharmacy. When asked how she viewed creativity:

> I think that just being able to look, really meaningfully interact with it, and feel comfortable being like, 'well, this isn't really something we did [in] class, but it makes us math.' Because that's a really cool thing, is you kind of do whatever you want as long as it's like within the boundaries of mathematics. *And so you feel comfortable enough to just mess around with it a little bit. That's really fun.*

She articulated how feeling comfortable allowed her to explore and examine the mathematics ('just mess around with it a little bit' and 'meaningfully interact with it') on her own terms and think through what it all meant, again with no urgency for the answer. Moreover, she found this enjoyable. To her, feeling comfortable was beneficial for feeling creative.

5.3.2. Originality: creating and expressing

We argue that viewing originality as part of creativity helps students feel creative, due to the emphasis on creating something new or of one's own as a means of expression. We provide a couple examples to illustrate how originality played a role in feeling creative for some students. A prototypical example of this is seen here, with Abbie, a White woman:

Interviewer: In your calculus I class, did you feel creative?

Abbie: We had to create and solve most of our own problems based on problems in the textbook and then we had a quiz where we had to create new mathematics where we had to create new theorems.

…

Interviewer: So why did you feel creative during those times?

Abbie: Because I was making up my own things and kind of creating.

Abbie said she felt creative when creating (and solving) problems she had made up. She also cited an assessment where students created new theorems. She directly tied the act of creation and that it was something of her own as to why she felt creative.

Originality is also a vehicle for expression and a way to push at the boundaries of mathematics. Optimus, a White man majoring in computer science, explained,

> I think the most creative I felt was when I did that C++ program to do my homework … *Nobody told me to make the C++ program, nobody told me how to put it together, it was very satisfying* when I did get the result I wanted.

Optimus felt creative when he created a computer program to answer a calculus problem. He did this of his own volition, given that coding was not part of the class. When asked what it meant to be creative, he remarked further on the role of creation and invoked the idea of expression:

> So math, it's just creative in its own way because it [math] creates stuff, it creates functions, it creates products and results, and that's what anything creative is. *You know, when you're making something, you're making something to get a result of expression. And I think you could do that expression with math.*

He again brought up the notion of creating objects (functions, products, and results) as to why mathematics is creative. While he at first attributed this creation to mathematics itself, he then brought in a human element by saying that one can express themselves through creating mathematical objects. When pressed further, he talked more about people creating:

> Absolutely, you have to be creative if you want to further expand the math world … if you want to expand like how you can use certain things, you need to be creative about it. If you want to see if there (emphasized) is a new formula, we absolutely have to be creative. *You have to create something.*

He argued that creativity was essential for pushing at the boundaries of mathematics and that creating mathematical objects was necessary for this.

5.3.3. Not feeling creative: understanding and application

We also investigated the reasons the 10 NC students reported as to why they did not feel creative. There were 4 major reasons, with links to the 2 themes that were more prevalent among the NC students: *Understanding* and *Application*.

First, some students reported not feeling they were good at mathematics and not enjoying the subject. Two students, Kaia Anderson (Black woman) and Mary (Hispanic woman) stated that math was not a favorable subject for them. For example, Mary stated, 'I think that's just me. I think that's just the mental block that I have for math'. It is sensible then that in not enjoying the subject, they felt they were not capable of creativity.

Second, some students reported not feeling creative because they were focused on understanding. Estella (Hispanic woman) was 'just learning things', whereas Shy-Ann (White woman) did not see the need for creativity as she was struggling to understand the content.

Estella: So I guess like just realizing that math isn't just on a piece of paper. It's all around you is my [take on creativity]. And sometimes I don't try and find the math. The math that's around me. (laughs)
Interviewer: And then in this course. Did you feel creative?
Estella: Not really, no. I felt like I was just learning things.
—
Interviewer: Did you feel creative in this course?
Shy-Ann: Yes and no (chuckle). Yes, because I saw how, for once, how math can relate to (pause) like real life aspects, which I hadn't seen before in some cases. But then I also realized if I didn't know what was going on, then I didn't see the need for them [creativity by way of applications]. So if we haven't been taught how to do it yet or kind of an example or so on, then I didn't fully understand the need for these [creativity] assignments.

It is curious that both Shy-Ann and Estella both referenced the real-life aspects of the world around them; they viewed mathematical creativity as including *Applications*. However, Shy-Ann felt she needed more understanding of the content in order for her to feel creative with those applications. Later in the interview, Shy-Ann said, 'I think being creative maybe enhances the student's understanding or even activity within the class'.

A third reason students reported not feeling creative was due to priorities: students seeking to fulfill the requirements of the course. Theasi (Asian man) and Vivala (Hispanic woman) both expressed that they did what was required of them in the class and did not seek out creativity. Theasi stated, 'I just take the class and once I'm done with class and done with my stuff, I will do my own things that are unrelated to math to be creative.' Shy-Ann (White woman) reported not feeling the need to be creative, as she understood the content.

Finally, four students, Bil (African woman), Casie Kim (Asian woman), OK (White woman) and Peter Parker (Hispanic man), said that they only had one way that they knew or learned to solve problems. They cited the lack of different ways as a reason that they did not feel creative. Peter Parker stated, 'I guess just the way he taught. I just think like that's the way it has to be done. So I don't really see any other way.' In taking calculus for the first time, Casie Kim explained that everything was new to her, so she had to rely on the method that the professor taught them. This viewpoint is sensible, as Originality is oftentimes an extension of Different Ways: to find an original way is finding a different way that is also new.

6. Discussion

Specific to the student perspective, our previous work (Cilli-Turner et al., 2021) showed the existence of six themes in how students may view creativity. Here we found that the two themes *Originality* and *Attitudes & Actions* were more prevalent in students who felt creative compared to students who did not. *Understanding* and *Applications* were more prevalent in those who did not feel creative compared to those who did; we discuss potential explanations for these findings below. Students that did not feel creative were all historically marginalized in mathematics, with 8 POC and 2 White women as the 10 students. Additionally, students who did not feel creative cited one of the four reasons: they felt they had one way to do a problem, felt they were not good at mathematics, struggled with understanding the content, or had no desire to go beyond the requirements of the course. Across these four reasons, we found small connections to viewing creativity as *Applications* or *Understanding*.

Our data limits us to reporting whether these views are associated with feeling creative; we do not make causal claims. Our results align, however, with the existing literature confirming the importance of originality as well as centering the person (Leikin, 2009; Rhodes, 1961; Torrance, 1974). We argue that *Originality* may play an important role in feeling creative due to the creation of something new (e.g. mathematical objects such as functions, solution approaches, problems), as an act of human expression. Similarly, viewing creativity as *Actions & Attitudes* may be important for feeling creative as this view is instantiated by taking actions, having certain mindsets, or attributing conditions to helping one be creative. When exploring *Actions & Attitudes* further, having a sense of comfort stood out. In both cases, we argue that these two ways of viewing creativity are highly beneficial for helping students feel creative.

For students who did not feel creative, it is reasonable that they were more likely to talk about *Applications* or *Understanding* in their view of creativity. For *Applications*, one potential explanation is that for students who do not feel creative in math, they may look to the connections mathematics has to the real world or topics they care about, for mathematics to have value. Shy-Ann also linked *Applications* with *Understanding* to apply math to those real-life applications, which aligned with her view of mathematical creativity: 'if I didn't know what was going on, then I didn't see the need for [real-life applications].' In the *Understanding* category, a number of students discussed feeling like they needed to understand the basic content first before they could be creative. For example, one student said:

> But I also think that it's important to understand the basics before you start being creative, because sometimes I think that can cause problems in making sure students know that they're on the right path to get to the answer, because sometimes if we're creative before that step you can lose students. Like they'll be really confused for the whole class. (OK, White woman)

Another student referenced the idea that understanding allows one to then be flexible: 'I feel like once you have an understanding of the material, you have more flexibility to be creative' (Vivala, Hispanic woman). For a number of students, including those whose aim was to just satisfy the requirements of the course, creativity was seen as something extra, an 'enhancer' as Shy-Ann said.

While viewing creativity as *Different Ways* was the most popular view of C students, there was not as stark a difference in this view between the C and NC groups. This suggests *Different Ways* may not be a differentiator in terms of feeling creative or not. We speculate that viewing creativity as different ways is an entry point to valuing creativity based on the popularity of that view – seven of the ten students who did not feel creative held this view and four referenced it as to why they did *not* feel creative – as a way for students to buy in to the importance of creativity. However, we speculate that *Originality* and *Actions & Attitudes* may be stronger in helping students towards feeling creative. Moreover, our students from historically marginalized backgrounds who did not feel creative tended to not view creativity in this way, so a focus on *Originality* and *Actions & Attitudes* may help level the playing field in disparities between who feels and gets to be creative in mathematics by default.

Based on our findings, we have the following recommendations for calculus instructors to help students feel creative. First, we recommend that instructors begin by focusing on *Different Ways*. As this is a popular view of creativity for students, this is an easy entry-way for instructors to come up with or assign tasks that ask students to solve problems in different ways. Second, we then recommend that instructors focus on *Originality* and *Actions & Attitudes*, as these two themes distinguish feeling creative from not and so may provide the most rewards for our efforts. This may generally take the form of explicitly discussing creativity with students as originality and actions and attitudes we can enact. Instructors should also provide tasks that value originality by asking students to create their own mathematical objects or create their own problems and reflect on their work. For example, a task that asks students to come up with their own function that satisfies certain properties promotes the importance of originality. Another example is to give students mathematical facts or examples and ask them to come up with their own theorems, as Abbie reported about her quiz. Lastly, instructors should discuss actions, attitudes and conditions with their students that may be helpful for being creative, for example, working on a problem for a long time is not a sign of failure but distinguishing when to continue to sit with a problem versus move on. As future work, we are investigating actions teachers can take to help students feel creative, as well as guidelines for creating creativity tasks that promote themes such as valuing different ways.

Of the ten students who did not feel creative, the majority were from historically marginalized backgrounds and/or first-generation college students. This is worrisome, especially as the course was specifically designed to foster creativity. Creativity in mathematics, let alone confidence, is not culturally bestowed on these identities in the United States (Chevalier et al., 2009; Correll, 2001; Xie et al., 2015). The relatively high numbers of these students suggest that there may be systemic factors in which these students did not feel creative: from an educational system wherein mathematics is taught rigidly, to socio-economic reasons for balancing school with other priorities such as employment, to racism. There may also be humility at play here as well; it may be more difficult for students to directly claim they are creative.

We hypothesize that creativity may be a proxy for students' confidence and comfort. For example, Aon had enough comfort to 'mess around' with the calculus content, and she felt creative; it was 'cool' and 'fun' to her. Therefore, students who do not feel confident (and therefore sadly not perceive themselves as creative) may feel they are not doing well and may value understanding and applications to other disciplines in order to understand mathematics' relevance. Future work should examine the role of confidence in feeling creative as a mediating factor.

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