Teacher Actions to Foster Creativity in Calculus

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Fostering mathematical creativity in the classroom requires intentional actions on the part of the instructor. We examine the teaching actions that students in a creativity-based Calculus I course report as contributing to their sense of creativity. Based on interview data, we found the four overall types of teaching actions: Task-Related, Teaching-Centered, Inquiry Teaching, and Holistic Teaching. We discuss subtypes as well as concrete actions, to provide actionable steps practitioners can take to foster students' creativity.

Keywords: creativity, Calculus I, teacher actions

Educational efforts to prepare students for Science, Technology, Engineering, and Mathematics (STEM) related jobs need to be furthered to prepare the STEM workforce to tackle ill-defined problems with no clear solution paths (Wilson et al., 2017). Fostering creativity in mathematics classrooms help develops this (Leikin, 2014), but at the tertiary level such classroom experiences are often restricted to pre-service teachers (Shriki, 2010) or mathematics majors in upper-level courses beyond Calculus I (Zazkis & Holton, 2009). By the time mathematics is exposed as a creative subject, we have lost many potential STEM majors, due to the ways in which calculus serves as a gateway course (Moreno & Muller, 1999). We argue that creativity must be fostered as early as Calculus I.

The role of teachers in fostering students' mathematical creativity is crucial. Moore-Russo and Demler (2019), citing Aiken (1973) stated that "teachers [are] the keys to unlocking creativity in the classroom" (p. 1). This is furthered by Hershkovitz, Peled, and Littler's (2009) statement: "creativity in mathematics classroom[s] can be improved through appropriate teaching methods" (p. 255). However, most discussion of how to foster creativity has been theoretical and/or at the K-12 level (e.g., Levenson, 2011, 2013). There is a need for actions tertiary instructors can take that are grounded in empirical data. In this paper, we explore teacher actions, as reported by undergraduate students, that fostered their sense of creativity in a creativity-based Calculus I course. Using qualitative coding, we present types and subtypes of actions that students discussed in interviews to provide practical actions that instructors can take.

Conceptual Framework & Background Literature

Creativity

We take a stance that mathematical creativity is relative to the student (Liljedahl & Sriraman, 2006; Zazkis & Holton, 2009); if any item (process or product) is new to the student then that is an act of creativity. This perspective differs from absolute creativity, which requires an item to be new to the field of mathematics (Kaufman & Beghetto, 2013; Leikin, 2009) to be considered creative. This discussion of relative versus absolute creativity is also reflected in the psychological literature, discussed as Big-C creativity (absolute) versus little-c creativity (relative) (Beghetto & Kaufman, 2007; Levenson, 2011). In educational settings, where the goal is to support students, relative creativity may be most relevant. We therefore take a developmental perspective on creativity: that a person's creativity can and does develop over time (not fixed). The main focus of investigation then is a person's process and actions, as opposed to the product created (Kozbelt, Beghetto, & Runco, 2010). Given that a person's creativity can change, this implies creativity can be honed by an instructor's processes and actions.

Teacher Actions

We consider a teaching action to be any act (physical, written, or verbal) in or out of the classroom that can be attributed directly to the teacher. Teaching actions share similarities to teaching practices (e.g. Ponte & Chapman, 2006). According to Ponte and Quaresma (2016), these actions can be "framed by two basic elements: the tasks proposed to the students, and the communication processes that take place in the classroom" (p. 52). Teacher actions have been one of the important constructs of research studies within inquiry-based and inquiry-oriented teaching. For example, Kuster et al. (2018) identified "four primary components of inquiry-oriented instruction: 1) generating student ways of reasoning, 2) building on student contributions, 3) developing a shared understanding, and 4) connecting to standard mathematical language and notation" (p. 2). For each component, Kuster et al. provided examples of instructional actions. For instance, when generating student ways of reasoning, Kuster et al. stated a description in action, including: "The teacher explicitly asks students to share their approaches to the tasks and the reasoning the students used to complete those tasks" (p. 6). In this paper, we follow a similar trajectory of categorizing creativity-oriented instruction through providing specific and explicit actions as reported by students that fostered their mathematical creativity.

Actions to Foster Creativity: K-12 & Tertiary

Actions to foster mathematical creativity proposed in the literature at the tertiary level are largely theoretical or conjectural (Sriraman, 2005). At the lower grades, Levenson (2011, 2013) explored fostering mathematical creativity at the 5^{th} and 6^{th} grades. Levenson (2013) found concrete actions that fostered creativity: "choosing appropriate tasks, fostering a safe environment where students can challenge norms without fear of repercussion; playing the role of expert participant by providing a breakdown of the mathematics behind a process; and setting the pace, allowing for incubation" (p. 273). Both Sriraman's theoretical principles and Levenson's empirical findings agree with some of the educational psychology literature, including Cropley's (1997, 2018) nine categories of fostering creativity. Levenson (2011, 2013) is one of the few that identified concrete actions grounded in data of fostering creativity.

In the context of tertiary education, Zazkis and Holton (2009) spoke about one crucial aspect of fostering creativity: "for a student to be creative, the instructor has to provide a problem where creativity can be shown" (p. 346). They included tasks in specific topics (e.g., graph and number theory). The authors suggested other tasks, including Watson and Mason's (2005) learner-generated examples, Leikin's (2013) multiple-solution tasks, and Shriki's (2008) explicitly valuing creating new mathematical concepts. They concluded with some teaching actions that "attend to the 'flow' of students' thinking, rather than setting the boundaries of formal mathematical curriculum" (p. 361). Shriki (2010), focusing on pre-service teacher education, furthered the research by allowing students to create new geometrical concepts and questions over the course of six weeks. They starkly stated, "Refraining from development of creativity in the classroom conveys the impression that mathematics is merely a set of skills and rules to memorize, and in doing so, many students' natural curiosity and enthusiasm for mathematics might vanish" (2010, p. 161-162).

We aim to complement these existing, mostly theoretical or conjectural work, by supplying ways of fostering creativity through practical actions that instructors could apply in their tertiary Calculus I courses. Given the need for actions grounded in data, coupled with the need for more creativity in calculus (Ryals & Keene, 2017), our research question is: *What are the teaching actions that calculus students have reported as fostering their sense of creativity?*

Methods

Participants were 34 undergraduates enrolled in Calculus I courses across various institutions in the United States. This study is part of a larger NSF-sponsored research project investigating fostering mathematical creativity in calculus. Participants were spread across two cohorts: Spring 2019 (C1) and Spring 2020 (C2). Twenty-four students identified as female (four bi-racial, five Latina, four Black, two AAPI, one Persian, eight White), nine as male (one bi-racial, one AAPI, one Latino/Hispanic, six White), and one as non-binary (White).

Instructors who taught these courses took part in a weekly online professional development about fostering creativity in Calculus I as part of a larger NSF-funded grant, where they designed and implemented at least six creativity-based tasks (El Turkey et al., 2020) and used a reflection rubric for creativity (Karakok et al., 2020) in their classroom.

Data Collection, Sources, & Analysis

We conducted semi-structured interviews with all participants. Interviews lasted 45-90 minutes long and took place over video conferencing software. The researcher asked questions such as "Did you feel creative in this course?", "Why and when do think you were creative?", "What have you learned about your mathematical creativity from this course?", and "What aspects of this course contributed to your or your classmates' creativity in the course?" Interviews were transcribed using a third-party transcription service and uploaded to the software nVivo™ for further analysis.

Because our theoretical stance was students' relative mathematical creativity, we examined each student's response to "Did you feel creative in your Calculus 1 course?" If they answered "yes," we looked at the reasons they gave for why they felt creative. If they answered "no," we looked at actions stated in the follow-up questions about their peers' creativity in the classroom. This was to account for students who did not see themselves or may not have felt comfortable stating they were creative during the interview but perceived a fellow classmate as creative. Two authors used holistic coding (Saldaña, 2016, p. 142) to identify (1) teacher actions: any student utterance about what the teacher did in reference to themselves or the class as a whole and (2) instances of creativity: any specific mention of creativity or answers to questions pertaining to mathematical creativity. In doing so, we identified teacher actions that fostered creativity.

For the first round of coding, we looked at the intersection of creativity and teacher actions, specifically if a student referenced a teaching action when talking about their own creativity. Two authors created teaching action nodes using a combination of descriptive and in vivo coding (Saldaña, 2016) and created 40 nodes. From those nodes, we used the process of theming (Saldaña, 2016) and organized them into five initial types based on emerging themes: *Task-Related*, *Assessment-Related*, *Teacher-Centered*, *Inquiry Teaching*, and *Holistic Teaching*. Within each of these types, we then read over all 211 instances of teaching actions mentioned and identified further sub-types. Due to the low number of instances and similarities in theme, we subsumed *Assessment-Related* under *Task-Related* as a subtype, resulting in four types.

Results

We created four overall types of teaching actions from analyzed student utterances related to fostering their own creativity. These types are separated into two overall categories, as inspired by Ponte and Quaresma (2016): actions that are part of the design of tasks and assessments, and actions that are part of the implementation of those tasks in class (See Table 1). These are teaching actions that the students reported as fostering their mathematical creativity in calculus; this does not consider teachers' perceptions of fostering creativity.

Table 1. Teacher actions reported to foster creativity, by type and frequency.

Type		Subtypes (with excerpts of teaching actions)
Design	Task-Related (76)	*Design High-Cognitive Tasks:* assign create new definitions, theorems, functions, and problems; assign solve created problems; assign problems that require making connections; give higher-order-thinking tasks
		Include Meta-Task Properties: provide group-worthy tasks, assign writing assignments such as journaling/reflections, revising homework
		Assessment-Related: assess open-ended questions, assess journaling assignments, assess creating new theorems, assess purposefully, de-emphasize correctness in assessment, does not assess drafts
Implementation	Teacher-Centered (18)	*Teacher Answers:* give different ways to solve problems, use online lecture videos, teach how topics are connected, review material
		Teacher Guides: foster understanding, persist to foster understanding, guide to correct answer, allow students to quietly work
	Inquiry Teaching (50)	*Allow for Discussion:* allow for discussion in class, allow for students to build (on other's thinking), divide class into groups
		Allow to Present: allow to present in class
		Teacher Active Listening: be aware of students' actions, encourage participation, inquire into students' thinking

Holistic Teaching (67)	*Encourage Mathematical Behavior:* prompt and encourage different approaches or divergent thinking; de-emphasize correctness in class; allow students freedom of time; use of the Creativity-in-Progress Rubric on Problem Solving tool (Karakok et al., 2020)
	Attend to Emotional Space: explicitly encourage students in their creativity, show excitement after student contributions, respect differences in the classroom

Within our dataset, the most frequently reported types were *Task-Related, Inquiry Teaching*, and *Holistic Teaching*. We focus our results on these three, as each had over 50 reported instances (out of 211). *Teacher-Centered* had the fewest: 18 instances. We defined *Teacher-Centered* as any action that was mostly focused on the instructor, whether it be verifying correctness or connecting topics. Given the low number and that they primarily consisted of typical teaching actions that many instructors already undertake, we do not expand on it here.

Task-Related

We defined *Task-Related* as any action that mentions properties of a mathematical content task that were (re-)designed, evaluated, or assessed by the instructor. Actions of this type were split into three subtypes. The first sub-type, *Design High-Cognitive Demand Tasks*, were made of teacher actions that were essentially about designing tasks with high cognitive demand (Stein & Smith, 1998). For example, Abbie (White woman, C1) discussed problem posing as fostering her creativity: "We had to create and solve most of our own problems based on problems in the textbook." Bryan (White woman, C1) also talked about the choice of assigning word problems that provide a "need to understand the concept in order to solve the problem." She went on to talk about making a connection with "information we've already learned in previous things and applying it here or just being very um inventive and creative about how to solve the problem."

The next sub-type, *Include Meta-Task Properties*, were about overall properties of the task itself that were not necessarily part of high-cognitive demand tasks. These tasks were not content-focused, but rather prompted the students to think about their problem-solving processes or reflect on how others thought about content. For example, Sal (Biracial Filipina American woman, C2) stated that "I know we had one class about thinking creatively and how to approach a math problem in a creative situation or asking, are there? Is it possible to approach a problem with a different mindset or different mannerisms?" This also involved re-evaluating homework or getting together in groups to discuss homework that had been done, in order to "understand how we went through the process to get our answer" (Breezy, Mexican man, C2).

The last sub-type, *Assessment-Related*, consisted of any mentions of how an assignment was graded or of tasks on quizzes or exams. For example, Bryan shared how homework was graded on a complete/incomplete scale. Murphy (White woman, C1) also said that the instructor would "give them [problems] back to us with like a little bit more notes on it just saying like oh that's interesting. Like the way that you found that and if you like you could have done this or this and that was good." We note that there were very few reported instances of Assessment-Related actions (11). Moreover, most of the instances (7) were in reference to one instructor. We explore what this lack of students reporting Assessment-related actions could mean in the Discussion.

Inquiry Teaching

Inquiry Teaching was defined as any action that can be linked to inquiry-oriented (or -based) instruction. We center the definition of active learning on two previous studies: Shultz and Herbst (2020) and Kuster et al. (2018). Shultz and Herbst (2020) created the INQUIRE (inquiry-oriented instruction review) instrument with four constructs about in-class teacher instruction: "interactive lecture, hinting without telling, group work, and student presentations" (p. 532). With these understandings of inquiry-oriented instruction, we saw the following three sub-types in our coding: *Allow for Discussion*, *Allow to Present* and *Teacher Active Listening*.

Allow for Discussion actions were about student discussion and characterized by group work, including actions as basic as *divide the class into groups* for deeper attention to student thinking such as *allow for students to build knowledge.* JCRU (Black woman, C2), in response to what contributed to her creativity, stated: "we all are able to learn from each other and build off of other people's ideas. Or take it and add a little something or maybe change it a little bit to make it work and make sense for us."

Allow to Present actions were also about student discourse but in front of the whole class. For example, interactive lecture was one way that Amelia (White woman, C2) reported her instructor contributed to her sense of creativity. The instructor "would always ask, like, how someone solved something. And then she would ask if someone solved it in a different way. And so she kind of wanted us to think differently and have different solutions."

Teacher Active Listening actions were where the teacher attended seriously to student voices. Aon (Black woman, C2) said her professor was aware of students' actions in the classroom:

> We did the problem, but we did it in a different way. And she compared the two ways and told me, "what's good about this way? What's good about this way?" So I feel that right there, her showing us, the students, different ways to do different problems showed her creativity and showed how, like she's able to adapt to everyone's learning style, learning that everyone won't be able to learn something as quickly in one way.

Holistic Teaching

Holistic Teaching consists of any teaching actions that do not require a response from students yet psychologically build an environment for fostering creativity. Within this type, there were two subtypes: *Encourage Mathematical Behavior,* which encourages mathematical behaviors that lead to creativity, as well as *Attend to Emotional Space* which attends to the student's affect. For example, Jmenard (White man, C2) shared the impact of his instructor promoting students' different responses on the growth of his sense of creativity:

> We spent like a whole 10 minutes, just everybody coming up with their own, you know, thoughts of what are different examples and then we went through them all together and she didn't tell anyone that they were wrong. She was just like, 'Well, I don't think that is one. Can you try to prove me wrong' or, 'Yeah, that is one. Can you prove [to] me why you're right.' Or, you know, so and so forth. So you're not in a situation where there's only one and one acceptable answer…So then that's where the creativity side gets in, because you're not worried about just doing a bunch of homework and applying the formula and just essentially robotic type learning. To where it's so I can actually learn the material, get comfortable with it. And then when it comes time to applying it, I can apply it any which way I want. And as long as I can convince the teacher that I'm right, then I'm right, you know?

Attend to Emotional Space actions attended to students' emotional states, by including supportive actions. As an example, Jennifer (White woman, C2) discussed how her instructor encouraged creativity: "He always tried to show the different ways that we would solve stuff, because he knew that some of us did do it that way and some of us did this way. So he always encouraged that even if it wasn't the most conventional method to use he would always encourage everyone's methods." She also shared that "he would always get excited whenever we would answer the questions and everything. And that whenever we would be understanding [the content]. So, it was just nice to see that he was rooting for us, (laughing) I guess all the time."

Holistic Teaching was made up of actions where instructors relinquished some control of the classroom. Some of the creativity-fostering actions reported involved uncertainty in solutions or understanding and acknowledging that teachers can learn from students. For example, Frost (Native American/Latinx/white man, C1) stated:

> [T]here's never…any negative outcome whenever you try and fail with him. It's like 'Oh you tried this. That's a good idea. But maybe next time like or what else could you do in this situation?' and he'll make you think through it and then eventually you'll solve it yourself.

This shows the impact of how students feeling there are no negative impacts to their attempts can lead to positive attitudes and mathematical practices that feed into feeling creative.

Discussion

In summary, we themed teaching actions that Calculus I students reported fostered their sense of creativity: *Task-Related, Teacher-Centered, Inquiry Teaching,* and *Holistic Teaching*. We further split these into subtypes, to show the breadth of actions teachers can take to foster students' creativity. We provided practical actions, as examples within these types and sub-types, to provide actionable recommendations for instructors looking to further creativity in their Calculus I classrooms. We note that these actions are from the students' (not instructor) perspective. We did not corroborate whether instructors in fact did these actions. Given our lens of creativity and that the individual themselves is the ultimate judge of whether they felt creative (independent of their reporting of it to us), students' judgments of what their instructor did that actively contributed to their sense of creativity are most valuable.

A number of the *Task-Related* teaching actions corroborate findings within the mathematical creativity literature (e.g., Levenson, 2013) and our own previous findings regarding creativity task features (El Turkey et al., 2020), e.g., different approaches leading to one answer, posing problems and questions, allows for originality/novelty, and uncertainty. That these are reflected in what students report back (versus the instructor/task designer perspective) and that moreover stand out in memory for them confirms that students are noticing their importance.

Our work confirms Hassi and Laursen's (2015) findings that "…inquiry, collaborative problem solving, and class discussions seemed to foster students' creativity and flexibility, growth that also improved their learning in other classes, and in everyday life" (p. 17). Next steps include exploring the further impact of these teaching actions on students, namely on their affect. We will link specific teaching actions to specific affective or other desired outcomes, so that instructors can choose which teaching actions to focus on, given their classroom goals. Another step is to use the themes from this paper to analyze classroom video data to identify what the teachers in fact did. This work may serve as a basis for developing a Creativity-Fostering Teaching Guide for practitioners. Our results suggest that teaching to foster creativity does not require a complete redesign of a class but can be done in little changes by incorporating some of the actions listed here.

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