SOURCES OF EVOLUTION OF UNIVERSITY STUDENTS' VIEWS ON MATHEMATICAL CREATIVITY

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In a world that is in increasing demand for creativity, mathematics courses and programs need to shift from more routine and computational to more creative and problem-solving focused. We present preliminary results of a qualitative research study in which we examined students' perceptions of mathematical creativity in an introduction-to-proofs course. We conducted interviews with students as well as collected their reflection assignments at the end of the semester. Using a definition of creativity from a relativistic perspective, we analyzed interview data to describe how students' perspectives of mathematical creativity evolved throughout the semester and the sources of those shifts. Students shifted from previously not seeing themselves, others, or mathematics as creative, to believing they are creative. The sources found in the data are related to content and course design.

INTRODUCTION

Creativity has become one of the most sought-after skills for academia and industry employers (World Economic Forum, 2016) and the importance of creativity is now highlighted in curriculum-standard documents internationally (Askew, 2013). The number of studies examining students' mathematical creativity at the tertiary level and how to enhance it is slowly growing, but compared to the number of studies at primary and secondary school mathematics level, it is still sparse. In this qualitative study, we explored how students' perceptions of mathematical creativity evolved over the semester of an introduction-to-proofs course and the sources of these shifts.

THEORETICAL PERSPECTIVE & BACKGROUND LITERATURE

Our research projects on mathematical creativity are grounded in the *developmental* perspective of creativity (Kozbelt, Beghetto & Runco, 2010). The developmental perspective asserts that creativity develops over time and emphasizes the role of the environment in which students are provided authentic tasks and opportunities to interact with others. We operationalize mathematical creativity as "a process of offering new solutions or insights that are unexpected for the student, with respect to their mathematical background or the problems [they've] seen before" (Savić, Karakök, Tang, El Turkey, & Naccarato, 2017; p.1419). This definition focuses on the *process* (Pelczer & Rodriguez, 2011) of creation, rather than the product that is created at the end of a process (Runco & Jaeger, 2012). Moore-Russo and Demler (2018) examined the perceptions of U.S. faculty and staff participants from gifted mathematics programs and found that, through counts of coding using several creativity frameworks, mathematical creativity in education was more of a process than "a subjective experience" (p.23). This particular orientation allows us to keep a dynamic view rather than a static one to capture nuances in the individual's thinking. Furthermore, the definition takes a *relativistic* perspective—creativity relative to the student—in contrast to absolute creativity for the field of mathematics (Leikin, 2009). For example, Levenson (2013), using a similar view point, focused on the discussion of ideas put forth by individual students and how these ideas helped in developing a product of collective mathematical creativity in fifth and sixth grade mathematics classrooms. Levenson also emphasized the teachers' roles in facilitating these discussions.

While there is literature on mathematicians' and mathematics instructors' perceptions on mathematical creativity (Borwein, Liljedahl & Zhai, 2014; Sriraman, 2009), research on students' perceptions on mathematical creativity as well as classrooms that impact these perceptions has received less attention. In one of our earlier studies, we examined university students' and mathematicians' definitions of mathematical creativity using three process categories: taking risks, making connections, and creating ideas (Tang, El Turkey, Savić, & Karakök, 2015). We found that students rarely associated making connections with mathematical creativity compared to mathematicians (9% of students' responses compared to 38% of mathematicians' responses). This study alerted us to think about explicitly valuing and discussing the processes that are deemed to be important in developing mathematical creativity. In this paper, we explore the following research question: In what ways do students' views on creativity evolve in an introduction-to-proofs course which explicitly valued mathematical creativity?

METHODS

Data were collected in an introduction-to-proofs course at a small liberal arts college in the Southwestern United States. This course was taught using an inquiry-based learning (IBL) pedagogical approach, where students often worked in small groups and gave presentations to the class on their proofs. The instructor explicitly valued creativity by making use of the Creativity-in-Progress Rubric (CPR) on Proving (Savić et al., 2017), which is a formative assessment tool that students can use to persevere in proving and encourage creative processes. The rubric has two main categories: making connections and taking risks. The instructor gave assignments and exam questions where students had to use the rubric to assess their own or other's work.

At the end of the semester, 4 female and 3 male students agreed to be interviewed. Each student participated in a 60 – 90-minute semi-structured interview where they were asked to describe the course, discuss their views on creativity, and discuss the use of the CPR in the course. Interviews were coded using hypothesis coding (Saldaña, 2013) and five categories were extracted from the research questions of a larger project; one of the categories being creativity. Three of the seven participants' transcripts were coded separately by the first and second author with 97% agreement. Because of this high degree of interrater reliability, the rest of the transcripts were coded by only the first author.

RESULTS & DISCUSSION

Three students who identified as females reported an explicit shift in how they thought about creativity or how they saw themselves as creative people. These changing perspectives stemmed from two sources: content and course design. Stephanie (all names are self-chosen pseudonyms) talked about content with respect to *learning new tools* to work with:

> I think I started to look at creativity a little bit different through this course...Prior to this it's been all very applied mathematics...So before, just using the trig equations to solve geometry was creative for me. Whereas now, this has just opened up a whole new door of opportunities for it because I can solve a proof using a contradiction, while somebody else used a contrapositive and somebody else used a direct proof and somebody else used induction, and we all do it completely different.

Whereas, Olivia attributed shifts to the social structure of the course, where the environment was conducive for growth. Students were able to see each other as creative as the semester progressed:

> We kind of all went in with kind of not really feeling confident in our abilities to be creative, so it was really interesting to see students that were quiet, reserved early on like show their work later in the semester and they had done something like totally cool and amazing...So, I feel you know their ability, like their confidence levels went up and I could say that's true of me as well. So, I wanna say that it's, you know it wasn't that like all the creative people took this course because I didn't consider myself creative and I took the course, and I would say that that's probably true of other students as well.

Stephanie echoed Olivia's comment almost exactly:

> At the beginning of the semester, I think a lot of people in that class were very shy and quiet, and so it was kind of hard to judge where their creativity was because they weren't sharing it as much. Um, by the end of the course you had everybody speaking, you had everybody giving their opinions and how to work on things together, and you saw everyone grow. You saw everyone coming up with their own tools and tricks. And everyone was posing questions, not just the few of us that were outspoken to begin with. So you definitely saw growth in the class, um not only with the shyness but with the creativity, and coming up with their own ideas to change things and make them better.

Since the course was taught using IBL, students were encouraged to present their work to each other, especially if they approached a problem using a different method, thus some of these shifts seemed to again related to course design. That is, they seem to be a result of *seeing others' work as creative and reflecting it back on themselves*. For instance, Peyton said:

> I really, I really did not feel like I was being creative at all throughout the course. It really was just things in my head, it makes sense that led to a conclusion that made sense. But, considering that I thought other people were exceptionally creative, I kind of thought that maybe they though that about me too.

The most striking change is evinced by Peyton who went from not seeing mathematics as a creative subject to enjoying the creativity in mathematics.

> Interviewer: And in your reflections you said…'I think I am on the spectrum that generally believes that, believes there is no need for creativity in mathematics. That's been a key reason why I enjoy math. I know, I know if I get the answer then I have done it correct. There is a set process and if I learn the process then…I'll be successful'. So, do you wanna comment on that part?
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> Peyton: I…should have made that more in the past tense, because I believed that prior to taking this course…There has been, you can figure out problems and it's creative in the sense that you can figure out how, where you wanna start with the problem. But I like being able to know that if I am doing it correctly, the process correctly, then I will get to the answer… I enjoy knowing when I'm gonna do something correctly as opposed to just spending a lot of time and then not even knowing if it's gonna yield good results. But this course changed that quite a bit, because there really was no assurance that anything would be correct, but it still… required me to use different thought processes to get to a result hoping for the best, which was stressful to say the least, but still, it was fun.

CONCLUSION

These three females explicitly acknowledged that their previous perceptions of not seeing themselves, others or mathematics as creative shifted to thinking they or mathematics are creative. We found two main sources of these shifts a) *content* - having more mathematical tools to work with, b) *course design* - developing a mathematical community that allows students to see each other's creative work with opportunities to reflect and connect back to their own work. Thus, for these students, content and course design seem to be important sources in shifting students' perceptions of themselves, others, or mathematics as creative.

Furthermore, although Stephanie does not explicitly mention the CPR on Proving, she mentions two of the subcategories "Tools and Tricks" and "Posing Questions". By using the CPR on Proving, it is evident that this particular instructor's course design and teacher actions aimed to explicitly value and foster students' mathematical creativity. This facilitated the evolution of students' perspectives on mathematical creativity. We believe that the connection between course design and teachers' actions and ever-changing students' perspectives on mathematical creativity requires additional exploration. In particular, which teacher actions are more fruitful to afford such changes and what other course design features contribute to these changes are important questions to explore in tertiary-level mathematics courses.

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