THE IMPACT OF MATHEMATICALLY CAPTIVATING LEARNING EXPERIENCES

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Secondary students do not often have positive experiences with mathematics. To address this challenge, this paper shares findings of a design-based research project in which a mathematical story framework was used to design mathematically captivating lesson experiences ("MCLEs"). We provide evidence that designing lessons as mathematical stories shows promise. That is, students reported improved experiences in MCLEs when compared to randomly-selected lessons. The MCLEs also impacted the students' descriptions of their experience.

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How can mathematics be taught so that students describe the subject as amazing, surprising, and full of wonder? Unfortunately, most evidence to date suggests that these descriptors do not describe the typical student experience in mathematics in the United States; students have increasingly poor attitudes in mathematics as they advance into higher grades (Mullis, Martin, Foy, & Hooper, 2016). One way to respond to these poor mathematical experiences has been to explore how lessons can be aesthetically enhanced to increase student engagement and interest by drawing on the affordances of what makes literary stories compelling and pleasurable. Analyses of high school mathematics lessons with heightened positive aesthetic responses (e.g., student exclamations of "Wow!) have linked narrative moves (e.g., misdirection) with positive student aesthetic reactions, such as anticipation, curiosity, and surprise (e.g., Dietiker, Richman, Brakoniecki, & Miller, 2016).

Building on this work, this present study is focused on learning whether lessons that are intentionally designed as mathematical stories improve student experiences. Working with six high school teachers, 18 *mathematically captivating learning experiences* ("MCLEs") have been designed and tested using the mathematical story framework. This paper reports on the results of the first design-and-test cycle of a three-year project of design-based research (Edelson, 2002), addressing the question *What impact, if any, do lessons designed as mathematical stories have on student aesthetic experiences?* Our results suggest that even in their first iteration, the design and enactment of mathematical stories shows promise.

Theoretical Framework

For this study, *aesthetic experiences* describe the way in which experiences move or compel an individual to act, such as by asking a question, persevering through difficulty, or even laughing or gasping. Therefore, the study of aesthetic dimensions of an experience examines how a particular experience enabled the compelling effects (or lack thereof) to occur. Since the audience of an enacted mathematical story is arguably the students, the students' evaluation and description of the experience is an appropriate measure of its aesthetic value.

Here we take the perspective that mathematical sequences can be interpreted as a form of *mathematical story*—a designed sequence of mathematical events (such as tasks or discussions) experienced by students connecting a beginning with its end (Dietiker, 2015). Mathematical stories have a plot, which enables the description of how a sequence can generate suspense (by setting up anticipation for a result) and surprise (by revealing a different result than the one anticipated). In this study, we use the math story framework as a conceptual resource for design.

Methods

Three pairs of experienced teachers were recruited from three high schools in the Northeast of the United States to design and test MCLEs. Each high school was selected to offer contrasts: (1) a small independent charter school with mostly Latinx students and a subject-specific curriculum, (2) a large public school with a very diverse student body (representing multiple ethnic groups) and an integrated curriculum, and (3) a large public school with a majority white student body and a subject-specific curriculum.

To prepare teachers to design MCLEs, the six teachers attended a two-week professional development in Summer 2018 at which lesson design was studied along three dimensions: captivation, coherence, and cognitive demand. The captivation and coherence dimensions were directly addressed through the mathematical story framework. A focus on the cognitive demand framework (Stein, Smith, Henningsen, & Silver, 2000) was also included to encourage to incorporate mathematical complexity as they designed MCLEs for curiosity and/or suspense.

Following the professional development, the teachers met weekly in pairs with researchers to design three MCLEs per teacher. Courses of focus were chosen to provide a wide array of topics, grade levels, and tracked levels (i.e., honors or non-honors). Teachers selected content based on topics that they had difficulty motivating in the past. Non-mathematical aspects (e.g., real-world contexts, games) that would likely influence student interest were avoided. In addition, the entire group of teachers and researchers met three times throughout the school year to share the emerging MCLE designs and get feedback from teachers from different schools.

At the start of each school year, all students were given a disposition survey using Likert items from TIMSS (2016) and the TRIPOD (Ferguson & Danielson, 2015) to measure captivation (e.g., do you like math?) and student perceptions (e.g., does the teacher care?) on a scale of 1 to 4 (see Riling, Dietiker, Gibson, Tukhtakhunov, & Ren, 2018 for more information). An aggregate "captivation" measure was then generated for each student using this instrument.

To learn if lessons designed as mathematical stories can improve the experiences of high school students, we compared the reported student experiences for MCLEs with randomly selected lessons taught in the same classrooms. In addition to 3 MCLEs per teacher, between 2 and 4 non-MCLEs per teacher were also observed. A single protocol was used to collect data for all enactments so that students would not know which lessons had a special design. After each lesson, we collected Lesson Experience Surveys (LES) for each participating student. The LES asks students to select three descriptors (e.g., intriguing, dull), displayed in a random order, and asks them to rate how they felt during the lesson from very bored (1) to very interested (4) (see Riling, Dietiker, & Gates, 2019 for more information). It also asks students to rate whether they found the content of the lesson challenging or not and to indicate to what level they agreed with statements such as "time flew by" and "the content of this lesson was relevant to my life."

Through prior work, we found that the more a student reports liking mathematics overall, independent of any particular lesson, the more they are likely to report positive experiences with a mathematics lesson ($R = 0.423$). Because of this relationship, we factored in students' mathematical captivation level when comparing MCLE and non-MCLEs. We also controlled for the teacher in order to acknowledge that students who learn from the same teacher and learn in the same classroom have related mathematical learning experiences.

Findings

Overall, the emerging results suggest that MCLEs improve the lesson experience of students and can alter the types of experiences students report.

The Impact of MCLEs on Student-Reported Lesson-Specific Interest Measures

Of the 8 classes in this study, 7 showed an increase in average student interest (on a scale of 1 to 4) with MCLEs. Table 1 displays the distribution of classes, along with the course and grade level and the average number of students surveyed across the observed lessons.

Table 1: Distribution of Classes (where "124" = school "1," teacher "2," and period "4") with subject, grade level, and interest measures for MCLEs and non-MCLEs

Class	Subject	Grades	Non-MCLE Avg. Rating (n)	Avg. MCLE Avg. Rating (n)	Difference
113	Algebra 2	10	2.71 (n=17)	2.89 (n=17.5)	+0.18
116	Algebra 2	10	2.81 (n=16)	2.94 (n=18)	+0.13
124	AP Calculus	12	2.60 (n=15)	2.92 (n=13)	+0.32
215	Integrated Math 3 H	10, 11	2.85 (n=24)	3.06 (n=21)	+0.21
224	Integrated Math 1	9	3.04 (n=15.5)	3.56 (n=13.5)	+0.52
311	Algebra 2	11, 12	2.76 (n=12.3)	2.77(n=15)	+0.01
322	Geometry	10	2.67 (n=12)	2.80 (n=10)	+0.13
327	Algebra 2	10	2.33 (n=10.5)	2.62 (n=9)	+0.29

At the student level, this improvement can be modeled. The graph in Figure 1 shows the linear regressions for the student interest measure by captivation for non-MCLEs and MCLEs. The influence of an MCLE on student interest in a lesson is statistically significant when taking into account student captivation and teacher, improving student experience by 0.21 ($p<0.001$). However, we did not find a statically significant difference between non-MCLEs and MCLEs on other measures, including student perception of challenge or whether time flew by.

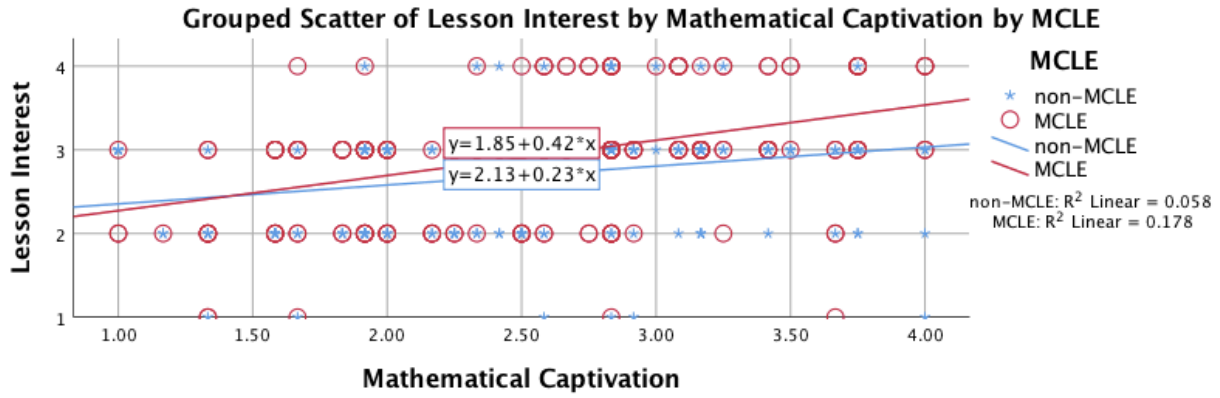

Figure 1. Scatterplot of student measures: Lesson Interest, from the Lesson Experience Survey, by Mathematical Captivation, from a survey of mathematical disposition

Overall, MCLEs appear to differentially influence the experiences of students with different mathematical dispositions. On average, MCLEs did not change the general experience of students with the lowest lesson experience, while students with very positive views of mathematics saw the most benefit. For example, the models predict that a student with low captivation (1) will report similar interest in MCLE and non-MCLEs (non-MCLE: 2.36, MCLE: 2.27). Yet students with high captivation (4) benefit by a factor of 1.16 (non-MCLE: 3.05, MCLE: 3.53).

MCLEs were not experienced differently by students based on their gender ($p=0.089$). It is difficult to assess any impact of student racial identification on aesthetic reports, because the racial breakdown of each school in the study is so different that it is difficult to distinguish between the effects of a student's school and their racial identification.

The Impact of MCLEs on Student-Reported Lesson-Specific Aesthetic Descriptors

MCLEs appear to have also been successful in changing the type of aesthetic experience of the students. For example, the descriptor "intriguing" was selected on 28.0% of surveys after MCLEs, but by only 18.8% of students surveyed about non-MCLEs. On the other end of the spectrum, 6.6% of students selected "dull" to describe MCLEs, compared with 15.4% of students selecting this descriptor for non-MCLEs. In addition, when analyzing whether MCLEs received more positive, neutral, or negative aesthetic descriptors, we found that students who experienced both types of lessons used more positive descriptors when describing their experience with MCLEs and that this difference was statistically significant ($p=0.001$). Overall, students used positive descriptors 58.1% of the time when describing MCLEs (compared to 47.1% for non-MCLEs), while using negative descriptors 11.1% of the time for MCLEs (compared to 17.3% of the time for non-MCLEs).

Even among MCLEs, the descriptors selected by students varied. For example, students were less likely to select descriptors that have extremely positive connotations, such as "amazing" or "fascinating" than other positive descriptors, such as "thought-provoking." The students who selected these extremely positive descriptors reported higher interest levels, on average, compared to students who selected all other descriptors with the exception of "suspenseful." An example of how different MCLEs are from each other is that 23% of students surveyed about an MCLE in class 224 about geometric transformations selected "amazing," while 24% of students surveyed about an MCLE in class 215 about finding the roots of a polynomial function selected "fascinating." These classes both had high levels of student interest among both students who selected these descriptors and those who did not. For these MCLEs, the students in class 224 reported an average interest level of 3.46 and the students in class 215 reported an average interest level of 3.20; these MCLEs had a high positive impact given that the average interest level reported across all student surveys is 2.84.

Discussion

With persistent negative views of mathematics by students, particularly at the secondary level, there is a pressing need to identify ways to improve the experiences students have with mathematics. Already from our early results, we are encouraged by evidence that designing for a more positive experience is possible, and are hopeful that providing students with more captivating lesson experiences such as these can impact their views of mathematics as a whole.

In addition to designing for improved reactions overall, our work thus far suggests that it is possible to design for specific aesthetic opportunities, such as suspense and surprise. We are also heartened that students find MCLEs to be more "intriguing." As the MCLEs go through more design cycles, we are interested in learning if more students will continue to report these aesthetic responses along with others.

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