Physics through Algebra for Preservice Elementary Teachers: A Comparison of Asynchronous and Hybrid/Face-to-Face Learning

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Abstract:
At a large Hispanic-serving Institution in the southwestern United States, physics was integrated into an algebra content course for preservice teachers. Due to the pandemic, content was asynchronously taught during the fall 2020 semester. During the fall 2021 semester, content was taught in both hybrid and face-to-face format. This research question was: Regarding preservice teachers' leaning and academic experiences, what were the differences between perceptions of preservice teachers' learning on the subject of physics-based algebra in an asynchronous format compared to a hybrid or face-to-face format? Data were gathered from both preservice teachers and their instructors. Data from preservice teachers showed that the in-person and hybrid instruction cohort saw a significant change in Personal Mathematics Teaching Efficacy from pre- to post-test when testing at the .05 level, whereas this was not the case for the online instruction cohort. There was no statistical difference in the post Personal Mathematics Teaching Efficacy and post Mathematics Teaching Outcome Expectancy scores between the face-to-face and hybrid preservice teachers and the asynchronous preservice teachers. Their instructors felt that experiences were more fruitful in a face-to-face format.

Keywords: physics education, mathematics education, STEM, asynchronous learning, hybrid learning

Introduction

As part of a redesign effort, physics was integrated into an algebra content course at the university level for preservice elementary school teachers. Their university instructors were trained to use face-to-face curriculum for a five-week unit to take place from the fifth week to the tenth week of a semester. The new content focused on helping preservice teachers make sense of algebra using physics (Grawe, 2011; Hitt, 2002; Hughes-Hallett, 2003); they were to use real world examples and movement to explain the meaning of slope and y-intercept. We built lessons that had physics-based algebra. Due to the pandemic, the curriculum was converted into an asynchronous format. While not ideal, the transition was necessary because of the insecurity regarding the modality caused by required social distancing. In the following year, the curriculum was taught in a hybrid format. To research the difference between asynchronous and hybrid learning, we investigated the following research question: Regarding preservice teachers' leaning and academic experiences, what were the differences between perceptions of preservice teachers' learning on the subject of physics-based algebra in an asynchronous format compared to a hybrid or face-to-face format? IRB approval was received for this research from both the elementary preservice teachers and their instructors.

Review of the Literature

Michelsen (1998) reviewed various theoretical arguments provided by numerous authors that all emphasize that development of a mathematical concept is a process that starts with an action on objects. The link between concept and actions can be taken to imply that students can use physical experimentation in a science context as a starting point to get acquainted with a mathematical concept. Indeed, there is a vast amount of literature on the integration of mathematics and science instruction. For example, Berlin and Lee (2005) surveyed nearly 1,000 relevant documents, noting a recent trend towards emphasizing high school (rather than middle or elementary school) curricula. However, almost invariably, the instructional context is either a science course or an “integrated” mathematics/science course. Only very rarely have there been published reports of mathematics courses that are based upon the use and modeling of science experiments.

Basista and Mathews (2002) reported on an integrated mathematics-science professional development program for middle and secondary school science and mathematics teachers. There are other reports that focus on courses for preservice elementary and middle school teachers, such as those by Lonning and Defranco (1994) and Koirala and Bowman (2003). Stohlmann (2018; 2019) reviewed a number of studies in which science contexts were used for middle school mathematics instruction, although they all dealt either with life-science or technology-oriented contexts; none were based on fundamental concepts of physical science.

Most of the reports dealing with mathematics-specific courses are at the college level or the high school level; rarely, are they at the middle school and elementary school levels. Examples of the former are Dolores-Flores et al. (2019), Oty et al. (2000), Elliott et al. (2001), and Wagener (2009). In Denmark, Michelsen (1998) used activities involving radioactivity to teach about exponential functions in a tenth-grade class that integrated mathematics and physics.

A handful of reports deal with specific mathematics instruction at the middle school level. For example, Town and Espinosa (2015) have provided a brief but clear discussion of how certain motion activities may be used to teach graphing and slope. Their students were able to apply an understanding of linear graphs and y-intercepts to predict the motions of toy cars successfully. A far more detailed and extensive project has been carried out by the “Mathematics Infusion into Science Project” (Russo et al., 2011; Burghardt et al., 2015; materials online at MISP, 2017). This project developed a suite of instructional materials for incorporating mathematics concepts in science classes, at a range of levels of technical complexity. McHugh et al. (2018) reported an assessment of the MISP project, and described in some detail a graphing activity based on a thermal conduction experiment.

Apart from the use of science activities and contexts in mathematics instruction, there are many reports of the specific difficulties involved in the mathematical preparation of preservice teachers. Greenberg and Walsh (2008) describe some of the inadequacies regarding the mathematical preparation of elementary preservice teachers on a national scale. For instance, Stump (1999) found that preservice teachers consistently failed to develop the concept of slope in real-world situations even though they will be teaching the conceptual and procedural aspects of this knowledge to future students. Byerley and Thompson (2017), in research to measure secondary teachers’ meanings for slope and rate of change, found that most teachers conveyed primarily formulaic meanings for slope and rate of change on a written assessment. An extensive review of studies that investigate the teaching and learning of slope in a variety of instructional contexts, including those involving in-service teachers, has been reported (in Spanish) by Abreu et al. (2020).

There has been a great deal of study of online versus in-person learning, with results varying widely depending on the details of the implementation. However, there do not appear to be many published research studies that address synchronous versus asynchronous methods of instruction in the types of physics activities described in this paper. A recent study by Guo (2020) directly compared the learning of two groups of students enrolled in an online physics course during the COVID emergency. The sole distinction between the two groups was whether or not they attended a two-hour synchronous virtual class offered three times every week. The group that attended the synchronous sessions had significantly higher learning gain than the non-attending group, and had a much smaller decline in their average exam scores compared to scores during the pre-COVID (in-person, synchronous) period of class. Although the sample sizes in this study were small and there are potential issues of self-selection bias, the results are nonetheless of great interest. In another study of learning in STEM subjects—primarily introductory physics—(Zipperer et al., 2021), students who attended Zoom lectures synchronously were significantly more likely to say that the material discussed during the lectures was explained clearly, in comparison to those who only watched the recorded Zoom lectures asynchronously. In a survey given to physics students at the University of Colorado (Wilcox & Vignal, 2020), many students said that synchronous instruction was more motivating than watching recorded lectures.

Methodology

Data were gathered from two sources: preservice teachers and their instructors. Preservice teachers' data took the form of measuring perceptions through the use of the Mathematics Teaching Efficacy Beliefs Instrument (MTEBI) (Enochs, Smith & Huinker, 2000). The MTEBI includes two subscales, the Personal Mathematics Teaching Efficacy (PMTE) subscale and the Mathematics Teaching Outcome Expectancy (MTOE) subscale. Data were gathered during the fall 2020 semester ($n = 268$) and the fall 2021 semester ($n = 212$). It was not possible to isolate data from the preservice teachers who took the course hybrid or face-to-face. Therefore, only semesters (fall 2020 versus fall 2021) were compared. There were no asynchronous courses during the fall 2021 semester—only face-to-face (meeting two days a week for 1:15 minutes per day) or hybrid (meeting one day a week for 1:15 minutes).

University instructors' data were gathered from an interview following the completion of the fall 2021 semester. These interview data were transcribed and coded for themes. University instructors were asked about the difference between the three different formats.

Results

Within the preservice teacher data, we compared data from the fall 2021 PST cohort with the 2020 PST cohort (which had the curriculum delivered in an asynchronous online format) and found similar patterns. Five of the items that showed statistically significant pre- to post-changes in 2021 also showed the same for 2020. For four of these, the effect or magnitude of change was larger in 2021 than in 2020. Overall, the 2021 in-person and hybrid instruction cohort saw a significant change in PMTE from pre- to post-test when testing at the .05 level, whereas this was not the case for the 2020 online instruction cohort. Our analysis indicates that this was because the 2021 cohort's mean baseline/pre-test PMTE score was lower than the 2020 cohort's mean baseline PMTE score while the 2021 and 2020 mean post-test PMTE scores were similar; thus the 2021 PST cohort had a larger gain in PMTE (3.5%) than the 2020 cohort (1.4%). There was no statistical difference in the post PMTE and post MTOE scores between the 2021 and 2020 cohorts. Analyses were conducted using two-sample unequal variance t-tests in Excel.

Within the instructor data, three themes emerged. Theme One: Curriculum delivery improved in fall 2021 compared to fall 2020 due mainly to in-person instruction, which allowed for collaborative, hands-on learning. The instructors concurred that teaching the new physics-based algebra curriculum went much better in fall 2021, which was their first opportunity to fully implement the hands-on, exercises in person. *"For me, it was night and day from teaching it a hundred percent online … It was wonderful; much, much better. I really enjoyed exploring it with them." "The biggest thing was just being with them every single day and being able to tackle problems, answer questions, alleviate fear … because there's a lot of fearfulness sometimes in some mathematics."*

Theme Two: Hands-on learning was fun for students and instructors. The instructors observed that the new curriculum was well-received by students. *"We've had some really good feedback from them [the students]. The main thing is when you see them doing it, they are having fun. They're talking to each other, they're enjoying it. It is challenging, but it wasn't so challenging you wanted to give up by any means."* One student told an instructor that the new curriculum and instruction had changed the way that she thought about teaching mathematics.

Theme Three: Content from online instruction augmented and fruitfully enhanced in-person instruction. Videos developed for asynchronous, online instruction became resources for students to use during fall 2021. These did not replace attending class on a regular basis but were extra resources to help students understand key concepts, use their calculators, and review for the final exam. An additional advantage was that the videos presenters were instructors who may have different ways of explaining concepts than a student's current instructor.

Discussion

Both theoretical analyses and practical experience have shown that teaching mathematics concepts within a context of "real-world" applications and observations holds promise of providing more effective and lasting learning. Although a number of combined science-mathematics courses have been developed, there are very few reports of mathematics-focused courses that make direct use of science experiments to provide a learning context, and fewer still at the preservice elementary/middle-school level. We have developed mathematics learning activities that make use of physics-of-motion experiments to teach algebraic concepts of function, linearity, slope, and quadratic variation. We have incorporated these activities within a mathematics course for preservice elementary/middle-school teachers, and taught the course in both asynchronous online and in-person/hybrid modes.

In this research, we report changes in enrolled students' attitudes toward mathematics teaching after having engaged in the new curriculum. Preservice teachers were assessed both pre- and post-instruction with a validated survey instrument specifically designed to measure teaching efficacy beliefs among preservice elementary teachers. We found small but statistically significant improvements pre- to post-instruction on a subscale that measured preservice teachers' sense of efficacy in teaching mathematics. The changes in this measure were larger in the group that received in-person/hybrid instruction, in comparison to the group receiving asynchronous/online instruction. The in-person group also showed significant improvements overall across several subscales related to teaching efficacy beliefs, whereas the asynchronous online group showed improvement only on a single subscale. Comments from both instructors and preservice teachers indicated that the teachers' enjoyment of and engagement with the activities was significantly greater with in-person instruction, in comparison to the asynchronous online mode. Our results suggest that a relatively short intervention using physics-of-motion activities can improve preservice teachers' confidence in their mathematics teaching ability, and they also suggest that in-person instruction of this curriculum is more effective and better received than in asynchronous/online mode. This latter finding is consistent with the as-yet very limited literature that compares STEM learning in asynchronous and synchronous modes.

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