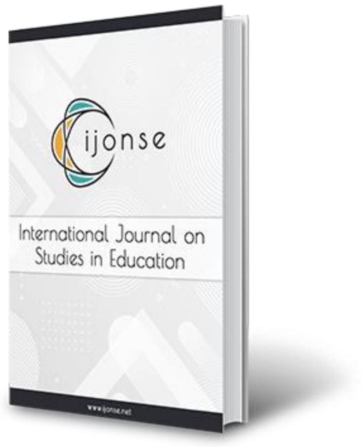

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Impact of Designed Task-Based Interventions on K-8 Preservice Teachers' Knowledge and Ability to Solve Measurement Unit Conversion Problems

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Impact of Designed Task-Based Interventions on K-8 Preservice Teachers' Knowledge and Ability to Solve Measurement Unit Conversion Problems

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Abstract

Converting two-dimensional measurement units presents challenges for K-8 preservice teachers (PSTs) (e.g., 9 ft^2 = __ yd^2). Place value deficiency, lack of understanding of metric system measurement units, misconceptions about relationships between measurement units, and uncertain knowledge of ratios have been identified as causes of student error in one-dimensional analysis (e.g., Livy & Vale, 2011; Morris, 2001; Southwell & Penglase, 2005). However, PSTs' strategies for solving two-dimensional measurement unit conversion problems (MUCPs) and possible interventions for improvement are rarely investigated in research. The purpose of this study is to design and test a set of tasks that may help students develop correct conceptions and skills for solving MUCPs with the emphasis on two-dimensional problems. The research question is: *What is the potential impact of designed task-based interventions on K-8 preservice teachers' knowledge and ability to solve MUCPs?* Data participants are 40 K-8 PSTs enrolled in a Foundations of Data and Geometry course. PSTs completed four MUCPs each in a pre-test and a post-test. Analysis of PSTs' results from both control and treatment groups show an improvement in the treatment group.

Introduction

The necessity to structure the curriculum such that students master measurement is discussed in the National Council of Teachers of Mathematics (NCTM, 2000) Standards, the Common Core State Standards for Mathematics (National Governors Association Center for Best Practices [NGA Center] & Council of Chief State School Officers [CCSSO], 2010), and the Next Generation Science Standards (National Science Teachers Association, 2012). Despite this, students often find units of measurement challenging, especially standard metric system units. Système international d'unités (SI), or the International System of Units, is internationally known as the standard metric system and widely used in the world. While the customary systems of measure are used daily in the United States, SI is the dominant system in international science, commerce, and trade (Thompson & Taylor, 2008). In a study on middle schoolers' misconceptions about metric conversion, Gilman (2013) found that grades 5-8 students had difficulty with converting units, regardless of the conversion direction.

Furthermore, Gilman observed that these students were more accurate with units smaller than a meter and more successful when converting length units than volume and capacity. Additionally, Sokolowski (2015) indicates that unit conversion errors are a common occurrence among students taking Advanced Placement Chemistry and Physics exams. Dincer and Osmanoglu (2018) suggested that their preservice science teachers lacked confidence in their ability to convert units outside of base units (e.g., grams, meters, or liters). This quasi-experimental study explores the impact of the researchers' designed task-based interventions on their K-8 preservice teachers' knowledge and ability to solve measurement unit conversion problems (see Appendix).

Literature Review

Importance of Measurement Unit Conversion Problems (MUCPs)

Previous research has underlined the importance of unit conversions to support student success in both science and mathematics. According to Ford and Gilbert (2013), conversions between units are taught in introductory science courses; therefore, being able to convert between units of measurement is essential to students' success in more advanced science classes. Butterfield et al. (2011) suggested that, in addition to supporting success in more advanced science, unit conversions are also critical for vocational science students; hence, conversions are important in lower level, applied science classes.

Although supporting students' success in science is important, Tucker (2009) stated that units of measurement should be integrated in mathematics as more than just a support for science. He argued that ongoing experiences with measurement units would help students build understanding of "equations, notation, and terminology" (Tucker, para. 3), because they could more easily connect classroom mathematics to real-world mathematics. The National Council of Teachers of Mathematics (NCTM) (2015) emphasized the need for students in the United States particularly to develop fluency in converting between SI and U.S. customary (i.e., English) systems to support their ability to "communicate in a technology-rich world and work in a global economy" (NCTM, para. 1).

How MUCPs are Taught in K-12 Schools

Given the importance of MUCPs in mathematics and natural sciences, it is natural to ask how unit conversions are typically taught.

Within the SI System

Raje (2019) found that roughly 32% of high school and middle school teachers in the study routinely spent class time on unit conversions within the SI system. Among them, only 25% of mathematics teachers spent time on such conversions, compared to 75% of their science counterparts. A little over 83% of these science and mathematics teachers stated that no questions or very few questions on standardized state high school assessments assessed students on converting units within the SI system. Approximately 67% of the teachers who spent class time on unit conversions acknowledged that most of their students were not comfortable performing metric conversions within the SI systems.

Convert from English to SI and Between Different Units in the English-SI System

Raje (2019) found that roughly 69% of middle school and high school science and mathematics teachers almost never required students to convert between systems in their classes; for example, from the English to SI system. About 93% of these teachers further indicated that no questions or very few questions on standardized state high school assessments even required students to convert between different units in the English-SI system

PSTs' Understanding of MUCPs

Even though solving MUCPs is a fundamental skill across mathematics and science (Raje, 2019), prior studies indicate that PSTs have limited knowledge of unit conversions (e.g., Liu & Alagic, 2013). Regarding PSTs' understanding of one-dimensional MUCPs, Aydın (2011) found that first-year science teaching students made mistakes in a General Chemistry II course due to their deficient understanding of mathematical concepts such as unit conversions. In particular, when solving a proportion/ratio problem, some participants incorrectly converted milligrams into grams. Similarly, prospective primary teachers in Birinci and Pırasa's (2010) study struggled with milligram to gram conversions. In Dincer and Osmanoglu's (2018) study of 73 prospective science teachers, over 50% of the participants indicated that they had difficulty with unit conversions and that this deficient knowledge hindered their success in their physics (90%), chemistry (41%), mathematics (15%), and astronomy (14%) classes. Overall, Dincer and Osmanoglu found that their prospective science teachers' had difficulty with MUCPs, especially when they were asked to convert outside of base units (i.e., outside of grams, meters, and liters). In addition to one-dimensional MUCPs, a few studies have examined PSTs' knowledge of two-dimensional MUCPs. Livy and Vale's (2011) study found that converting 3200 square centimeters to square meters was the most difficult test item for PSTs.. Out of 297 participants, only 28 (or 9%) gave a correct response, 266 (or 90%) provided an incorrect answer, and three (or 1%) gave no answer. Using this same task in their research, Dincer and Osmanoglu (2018) reported that 48% of their prospective teachers incorrectly converted 3200 square centimeters to square meters. The errors were due to either applying the one-dimensional relationship between centimeters and meters (i.e., 100 cm = 1 m), or being unaware of the correct two-dimensional relationship between square centimeters and square meters. In Kolar-Begović's et al. (2019) study on PSTs' prior knowledge of measurement, drawing representations of 1 cm, 1 dm, 1 cm^2, and 1 cm^3 were found acceptable (without any mistakes) by 82.52 %, 61.17 %, 35.92 %, and 29.13 % of the participants, respectively. This shows that the higher the dimension is, the more challenging it is for PSTs to conceptually understand units of measurement.

Purpose of the Study

Previous research has seldom reported on task design regarding two-dimensional MUCPs. The purpose of this study is to design and test a set of tasks that may help PSTs develop correct conceptions and skills for solving MUCPs with the emphasis on two-dimensional problems. The research question is:

> *What is the potential impact of designed task-based interventions on K-8 preservice teachers' knowledge and ability to solve both 1D and 2D MUCPs?*

Methodology

Overall Research Design

The overall study used a non-randomized control group, pretest-posttest design which is "one of the most widely used quasi-experimental designs in educational research" (Ary et al., 2010, p. 316). The pre- and post-tests included similar sets of MUCPs. The experimental group participated in a task-based interview. In the interview, the interviewer brought tasks within the *zone of proximal development (ZPD)* (Vygotsky, 1978) of individual students by working on the designed MUCPs using manipulatives and ongoing discussion between PSTs and the interviewer. The purpose of adopting such a research design is to analyze the potential impact of the targeted conceptual tasks on student understanding and problem solving of MUCPs.

Research Site and Participants

The study was conducted in a large, public, research university in the Southeast United States. The university has Carnegie classification as a doctoral-granting institution with "high research activity" and very high undergraduate enrollment. The university prides itself on being learner-centered despite its research focus and large size, with the intention to give students the feel and support afforded by a small teaching university. The focus in this paper is on the K-8 PST population. Over the past six years, 122 PSTs per year have graduated from the elementary certification program and 40 in the middle grades certification program. PSTs enrolled in the elementary certification program in that period of time were required to complete a 3-course sequence of mathematics content courses, while PSTs in middle grades program were required to complete a 4-course sequence. The focus course is titled *Foundations of Data and Geometry for K-8 Teachers*, which was the second course in both sequences. Participants in this study were 44 PSTs (38 in the control group and six in the treatment group) enrolled in three sections of this focus course.

Data Collection

Two sets of data were collected: class assessments (from all 44 PSTs) and task-based interviews (from six PSTs). Class assessments included the pre-test (the first midterm exam) and the post-test (the final exam), each of which contained four MUCPs. The four MUCPs were designed to be comparable in both exams in terms of the format and difficulty levels. Both sets of MUCPs involved pairings of one- and two-dimensional unit conversion analysis with contexts of U.S. customary and SI systems (see Table 1).

Table 1. MUCPs Used in Pre- and Post-Tests

	U.S. Customary MUCPs	SI MUCPs
One-Dimensional	Pre-test: 4320 in. = __ yd	Pre-test: 3069 g = __ kg
	Post-test: 349 in. = __ yd	Post-test: 5830 mL = __ L
Two-Dimensional	Pre-test: 16 ft^2 = __ $in.^2$	Pre-test: 545 mm^2 = __ cm^2
	Post-test: 10 ft^2 = __ $in.^2$	Post-test: 1400 cm^2 = __ m^2

[a] Even though mL and L measure volume (three-dimensional quantities), the nature of the conversion is one-dimensional

Task-based interviews were conducted with six participants separated into two individual sessions and two paired sessions. Initially, eight participants were divided into four pairs based on differing levels of knowledge and problem-solving ability as determined by the pre-test results. Two participants withdrew from the study, so the research team agreed to conduct an individual interview with each of the remaining partners. Since one researcher was the instructor of the research participants during data collection, she was completely excluded from the data collection process to guarantee the confidentiality of PST participation and increase data validity.

The interview protocol consists of semi-structured and open-ended questions. Each interview session lasted for approximately an hour and was video and audio recorded. Heuristic prompts were provided as needed to guide participants' thinking; metacognitive questions were asked to promote reflections (Goldin, 2000). The tasks were designed to connect to PSTs' prior knowledge and allow them to reach a higher level of understanding (Vygotsky, 1978). The tasks also incorporated the use of multiple representations (e.g., visual and symbolic) (Stein et al., 1996).

Data Analysis

Both the qualitative and quantitative data analysis methods were used for analyzing the two sets of data. For the interview data, the analysis included iterative alternations of inductive and deductive analyses. Individual open coding was conducted to identify participants' successes, challenges, and potential conceptual development in working on the designed tasks. Discrepancies among researchers were resolved through multiple rounds of group discussions. For the pre- and post-test data, the researchers first analyzed the pre-test results and categorized PST knowledge and problem-solving ability into five levels (see Table 2). The levels were used to pair up participants for taking the task-based interviews and later were used as the baseline data for the pre- and post-test comparison analysis. Basic quantitative analysis was performed to see the changes of levels between the pre- and post-tests across both the experimental (interview participants) and control (non-interview participants) groups.

Table 2. PST Knowledge and Ability Levels to Solve MUCPs

Focus of Levels	Criteria of Levels
Level 0 - focusing on minimal level of knowledge and ability to solve both one- and two-dimensional (1D and 2D) MUCPs	None of the MUCPs were correct.
Level 1 - focusing on knowledge and ability to solve 1D MUCPs	Case 1: one 1D MUCP was correct.
	Case 2: two 1D MUCPs were correct.
Level 2 - focusing on knowledge and ability to solve 2D MUCPs	Case 1: one 2D MUCP was correct.
	Case 2: two 2D MUCPs were correct.
Level 3 - focusing on moderate level of knowledge and ability to solve both 1D and 2D MUCPs	Case 1: one 1D and one 2D MUCPs were correct.
	Case 2: one 1D and two 2D MUCPs were correct.
	Case 3: two 1D and one 2D MUCPs were correct.
Level 4 - focusing on high level of knowledge and ability to solve both 1D and 2D MUCPs	All MUCPs were correct (including inefficient or slightly flawed processes and minor typo errors).

Results

PSTs' change in levels and correctness on the four items from the pre-test to the post-test are reported and compared below.

Overall Correctness and Level Results

Table 3 displays PSTs' averages in the correctness and levels (see Table 2 for level criteria). The control group PSTs across the three courses initially achieved an average level of 2.66 on the pre-test and 2.26 on the post-test, and an average correctness of 2.63 on the pre-test and 2.42 on the post-test. The treatment group PSTs scored an average level of 2.67 on the pre-test and 3.33 on the post-test, and an average correctness of 3.00 on the pre-test and 3.50 on the post-test. So the averages of the control group PSTs went down from pre-test to post-test by 10% in level and down by 5.25% in correctness, while those of the treatment group PSTs went up by 16.5% in level and up by 12.5% in correctness.

Table 3. PSTs' Averages in Correctness and Levels

	Pre-Test		Post-Test	
	Control (*n* = 38)	Treatment (*n* = 6)	Control (*n* = 38)	Treatment (*n* = 6)
Average Level (4 is highest)	2.66	2.67	2.26	3.33
Average Correctness (4 is highest)	2.63	3.00	2.42	3.50

Comparison of the number of PSTs across levels and treatment/control groups is shown in Table 4.

Table 4**.** Comparing PSTs across Levels and Treatment/Control Groups

	Pre-Test				Post-Test			
	Control (*n* =38)		Treatment (*n* = 6)		Control (*n* = 38)		Treatment (*n* = 6)	
Level 0	2	(5.26%)	1	(16.67%)	2	(5.25%)	0	(0.00%)
Level 1	9	(23.68%)	0	(0.00%)	16	(42.11%)	1	(16.67%)
Level 2	2	(5.26%)	1	(16.67%)	1	(2.63%)	0	(0.00%)
Level 3	12	(31.58%)	2	(33.33%)	8	(21.05%)	1	(16.67%)
Level 4	13	(34.21%)	2	(33.33%)	11	(28.95%)	4	(66.67%)

In the treatment group, almost all PSTs changed levels from the pre-test to the post-test, while 17 PSTs (almost half) in the control group did not change levels. One PST in the treatment group decreased by one level between the pre- and post-tests, and four PSTs increased by an average of 1.25 levels. Across the entire treatment group, an average PST increased by 0.67 levels. In the control group, 14 PSTs decreased by an average of 1.86 levels and seven increased by an average of 1.57 levels. Across the entire control group, the average PST decreased by 0.39 levels.

MUCP Type Results

In Table 5 below, the counts of PSTs who correctly answered each MUCP is shown. Comparing correctness of individual MUCPs reveals that the treatment group seemed to retain the information better because all PSTs improved their scores in three items by more than 16% or stayed stable on one item (US 2D). While in the control group, except for one item (SI 1D) seeing an improvement by 7.89%, scores decreased in three items by a few percentage points to 15.79% (US 2D).

Table 5. PSTs' Correctness

	Pre-Test				Post-Test			
	Control (*n* = 38)		Treatment (*n* = 6)		Control (*n* = 38)		Treatment (*n* = 6)	
US 1D	34	(84.21%)	5	(83.33%)	33	(81.58%)	6	(100.00%)
SI 1D	24	(60.53%)	4	(66.67%)	27	(68.42%)	5	(83.33%)
US 2D	26	(68.42%)	5	(83.33%)	20	(52.63%)	5	(83.33%)
SI 2D	16	(42.11%)	4	(66.67%)	12	(31.58%)	5	(83.33%)

In Table 6 below, we show a count of all PSTs in both control and treatment groups who answered a MUCP correctly on the post-test when they had answered incorrectly on the pre-test (gained a point) or the reverse (lost a point). More PSTs gained a point for the one-dimensional SI MUCP, while more PSTs lost points for US one-dimensional, US two-dimensional, and SI two-dimensional. The latter two MUCPs had the fewest correct answers on the post-test.

Table 6. All PSTs' Responses

	Gained 1 point	Lost 1 point
US 1D	3	4
SI 1D	9	6
US 2D	3	9
SI 2D	3	7

Discussions, Limitations, and Future Research

Overall, the study indicates the positive impact of the designed tasks on the treatment group PSTs' levels of knowledge and ability to solve MUCPs. Below the researchers share patterns observed in the data, limitations, and future research.

Discussions

The results of this study are in line with several studies in the literature. Similar to the PSTs in Livy and Vale's

(2011) and Dincer and Osmanoglu's (2018) studies, PSTs found the SI 2D conversion problem the most challenging among four types of MUCPs (9% and 48% answering correctly in Livy and Vale's and Dincer and Osmanoglu's studies respectively, versus 42.11% of the control group on the pre-test and 31.58% of the control group on the post-test in this research). Within the control group, correctness with both 2D problems decreased slightly on the post-test while the treatment group's correctness stayed the same on US 2D and increased by 16.66% on SI 2D. This suggests that improving 2D MUCPs seems more about conceptual understanding of measurement and dimensionality. Parma et al. (2011) recommended multiple activities such as building, drawing, completing, and representing arrays and incorporating both manipulatives and reasoning from various perspectives to challenge PSTs' measurement and dimensionality misconceptions.

For almost each problem, the SI conversion had a lower correctness percentage than the US conversion for both the treatment and the control groups. The US PSTs' familiarity with the metric system is relatively low (Raje, 2019), despite the dual-labeling of measuring devices or pre-packaged items. Thus, improving on SI 1D (but not SI 2D) conversion problems is more about knowing the metric relationships. Since SI is widely used in sciences, PSTs should be given more opportunities to practice on them. It is worth mentioning that the treatment group reached the same correctness level (83.33%) for both SI 2D and US 2D conversions in the post-test. It is encouraging to see the treatment group made an improvement on the relatively challenging conversion problems (SI 2D) when comparing their pre- and post-correctness (from 66.67% to 83.33%).

Although the treatment group reached a higher correctness percentage for almost all types of MUCPs (US 2D remained the same) on the post-test, the control group fell to a lower percentage on most of MUCPs except for the SI 1D conversions. It seems that the control group did not retain the knowledge well throughout the semester. One explanation for this phenomenon could be the "next-day phenomenon" frequently encountered by mathematics educators (Tzur & Simon, 2004). When learning a mathematical concept through hands-on activities in a specific context, students are able to anticipate the results of the problem solving. However, when the familiar context is not provided, students might lose the ability to anticipate the results of a similar problem-solving process even after a very short period of time such as the next day. Tzur and Simon argue that this phenomenon is not because students have forgotten the concept, but because their knowledge is only available within the context in which the knowledge was created. Students may be able to regain their knowledge of the concept when they reengage the previous activity, but they have not developed a mental activity to anticipate the knowledge without being limited to the specific context.

Limitations

There are limitations for this research to consider. First, the control group did not receive a "placebo" session, so we cannot conclude that the difference in two groups' performance was caused by the effectiveness of the task-based interviews. Second, two lower-level participants dropped out of the study, which might have caused a certain degree of bias in our data. And because the two participants dropped out, their partners had to take the interview individually, which might have also had some impact on their problem-solving performance. In addition, the size of the treatment group is small due to the predetermined course design.

Future Research

One direction of future work is to incorporate more 2D MUCPs within the SI context in mathematics content courses to improve PSTs' knowledge and ability in this area. The other direction is to introduce more cross-dimension MUCPs to PSTs to enhance their dimensionality understanding (e.g., converting from 1D to 2D). Through informal conversation with K-8 PSTs, one of the authors noticed some PSTs had never realized a point takes up no space. They were very concerned about how large a point should be in order to be a point. They showed similar surprises when discussing their understanding of the dimensionality of 1D, 2D, and 3D objects. This lack of dimensionality understanding could be a barrier to their learning of the conversion rules. Hence, we believe we should focus on creating tasks that dovetail with students' struggles in measuring various dimensions (e.g., length, area, and volume), cross-dimension conversions, as well as creating opportunities for self-reflection and critiquing reasoning.

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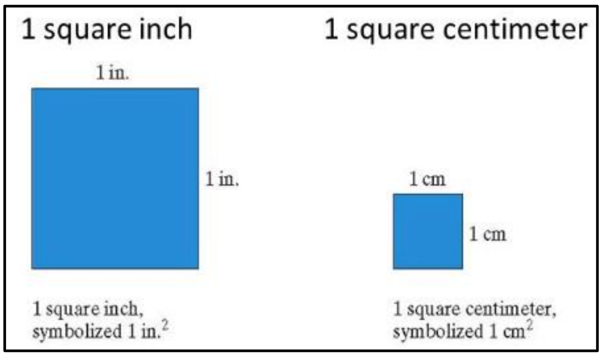
Appendix. Measurement Unit Conversion Learning Intervention Task (Beckmann, 2018; Parker & Baldridge, 2008)

- **Pre-task**: clarify the meaning of a unit square.
  - A **unit square** is any square whose sides are 1 unit long. The area of a unit square is called a **square unit**. For example,



  - The notation is designed so that one "squares" unites in the same way one squares numbers. For example, for a square whose sides are all 1 cm long,

    Area = 1 cm x 1 cm = (1 x 1) (cm x cm) = 1 cm^2
  - Note the terminology: a unit square is a geometric figure (a square), while a square unit is a unit of area.

- **Step 1**: start from the very basic one-dimensional unit conversion question.

Draw the relationship between 1 yard and the number of feet it contains. What about 10 yards and the feet? How would you solve this problem without drawing? Now can you draw 1 foot and tell how many yards there are? What about 9 feet and tell how many yards there are? How would you solve this problem without drawing?

- **Step 2**: transition to visual representation of the two-dimensional relationship.

Draw a square yard and a square foot. What relationship between them can you tell based on your drawing? What about 10 square yards and the number of square feet they contain? How would you solve this problem without drawing? Now can you draw 1 square foot and tell how many square yards there are? What about 18 square feet and tell how many square yards there are? How would you solve this problem without drawing?

- **Step 3**: move on to two-dimensional real-world applications.

A rug is 5 yards long and 4 yards wide. What is the area of the rug in square yards? What is the area of the rug in square feet? Show two different ways to solve this problem. Explain each case. A room is 27 ft long and 10 ft wide. What is the area of the room in square ft? What is the area of the room in square yd? Show two different ways to solve this problem. Explain each case.

- **Step 4**: expand to three-dimensional conversions.

A compost pile is 2 yards high, 2 yards long, and 2 yards wide. Does this mean that the compost pile has a volume of 2 cubic yards? Explain.
Determine the volume in cubic feet of the compost pile in two different ways. Explain each case.

- **Step 5**: evaluate others' solutions.

  - $1\ m^2 = 100\ cm^2$
  - $8\ yd^2 = (8 \times 3)^2 = 576\ ft^2$
  - $864\ in^2 = 864 \times 144 = 124416\ ft^2$
  - 43 ft = 14 yd 3 ft