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A Multistep Inquiry Approach to Improve Pre-Service Elementary Teachers' Conceptual Understanding

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Article Info	Abstract
<p><i>Article History</i></p> <p>Received: 29 May 2019</p> <p>Accepted: 10 September 2019</p> <hr/> <p><i>Keywords</i></p> <p>MSI inquiry Conceptual understanding Physical science Workbook</p>	<p>A quasi-experimental control group pre- and post-test study was used to determine the effect of a Multi-Step Inquiry (MSI) approach on pre-service elementary school teacher's conceptual understanding. The MSI study involved the development of a conceptual workbook, and a Physical Science Concept Inventory. The conceptual workbook has activities that explicitly target students' misconceptions in physical science. The inventory has three categories: forces and motion, heat and temperature, and electricity. Descriptive and inferential statistics were used to interpret the data. Independent t-tests were used to compare the experimental and comparison groups. Further, Cohen's d and Hake's g effect sizes were used to determine the effectiveness of MSI. Results indicated that the MSI approach as an effective teaching strategy for conceptual understanding. As such, the authors have made recommendations for both research and teaching.</p>

Introduction

Misconceptions pose great challenges to students' learning, regardless of educational level. Pre-service Elementary School Teachers have various misconceptions in physical science, something that is of great concern considering that these student teachers will one day be entrusted with an important role of introducing science to young students. The term 'misconceptions' in this paper refers to constructions that are usually not consistent with scientifically accepted ideas (Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001) or "conceptual or reasoning difficulties that currently exist and that the instructor must help the student remedy" (Modell, Michael, & Wenderoth, 2005, p. 22). Some researchers prefer the terms preconceptions, others; alternative conceptions, and yet others, alternative frameworks. There is a plethora of information about students' misconceptions in physical science for elementary school students, most of which point to the need for an ongoing discussion regarding effective instructional practices suitable for the preservice teachers (PSTs). A study by Sadler and Sonnert (2016) concluded that effective teachers are the ones who are able to identify students' misconceptions and also have adequate knowledge to address those misconceptions. Fouché (2015) further argues that identifying and addressing misconceptions constitute great challenges among educators. This implies that teachers are responsible for ferreting out these misconceptions from students and dealing with the misconceptions head-on. This is much easier when teachers themselves do not hold similar misconceptions as their students. Research has shown that elementary school teachers have similar misconceptions as their students (Asoko, 2002; Trundle, Atwood, & Christopher, 2009; Webb, 1992). This makes the task of addressing the misconceptions almost impossible. As such, there is a need for educators to focus on addressing physical science misconceptions in pre-service teacher education to alleviate this problem. Traditional instructional approaches do not usually address students' misconceptions (Prince, Vigeant, & Nottis, 2016; Schmidt, 1997).

Several researchers (e.g. Ginns & Watters, 1999) have investigated students' misconceptions and argued for the need for science educators to identify and implement more effective strategies for science teaching. Several proposed instructional strategies relate to active learning or inquiry-based learning (Cobern, Schuster, Adams, Applegate, Skjold, Undreiu et al., 2010; Cobern, Schuster, Adams, Skjold, Mugaloglu, Bentz, & Sparks, 2014). Inquiry based learning itself has multiple meanings across various educators (Brickman, Gormally, Armstrong, & Hallar, 2009; Brown, Abell, Demir, & Schmidt, 2006; Minner, Levy, & Century, 2010). Despite the ambiguities surrounding the meaning of inquiry, the National Research Council (NRC) (Olson & Loucks-Horsley, 2000) observes that common features of inquiry instruction may be noted. Thus, in an inquiry-based classroom learners (1) are engaged in scientifically oriented questions. (2) give priority to evidence, (3) formulate explanations from evidence (4) evaluate their explanations in light of alternative explanations and (5)

communicate and defend their proposed explanations. Based on these attributes, educators have a chance to investigate different approaches to inquiry. This study presents an instructional method that helps address pre-service teachers' misconceptions of physical science using a Multi-Step Inquiry (MSI) approach, which has the following features: (1) explicit discussion of misconceptions, (2) experimentations, and (3) discussion of the concepts for the second time, and (4) writing misconception focused essays. We investigate the research question "What is the effect of the MSI approach on students' conceptual understanding in physical science?"

Theoretical Framework

Piaget suggested a cyclic process by which conceptual change occurs in children (Heuer, 2006; Piaget, 1950). First, children assimilate information from their everyday experiences. In this case, the existing schema helps the children understand new information. If everything works, the child accepts the information, and this creates an equilibrium. However, when children acquire completely new information, they experience disequilibrium or discomfort. Then the children reevaluate their thinking and accommodate the new information. This is a complicated process and thus effective conceptual change needs systematic attention. Influenced by Piaget's theory, Posner, Strike, Hewson, and Williamson (1982), Posner et al., 1982, and Hewson (1992) developed conceptual change theory that includes adults.

According to Hewson (1992), students use their existing understandings and experiences to construct new knowledge. Hewson further observed that since people construct their knowledge based on social interactions, the misconceptions that people have may be prevalent within societies. As such, there must be recognition that the influence of societal interactions may limit how individuals learn new concepts. Another important note from Hewson is that although individuals may have similar experiences, they may get different conceptions from these experiences because of differences in the interpretations of the experiences.

Science educators encourage use of conceptual change curriculum to explicitly deal with these misconceptions. Posner et al. (1982) categorized students' learning in two forms: assimilation and accommodation. In assimilation, students use the knowledge they already possess to learn new material. In accommodation, students reevaluate their current understanding and change it in light of the new knowledge. Accommodation requires compelling evidence from educators to change the students' minds to accept the new knowledge because misconceptions are robust and thus do not change easily. As such, educators must be provided a rational path that leads to students changing their understanding based on available evidence (Posner et al., 1982). Thus, Posner and colleagues suggested three processes that students need to go through to change their misconceptions as follows:

1. there must be a dissatisfaction with existing conception,
2. the new conception must be intelligible, and
3. the new concept must appear initially plausible. (Posner et al. p. 216)

This indicates that teachers need to show students that their current ideas are not scientific. Instructors can effectively teach conceptual understanding if they understand that their job is to provide students a chance to interact with the material and activities and then make an informed judgement on which conception to accept (Hewson, 1992). This is not possible in situations where the teacher is just telling them the new conception. Then, the teachers must lead the students to a better understanding of the concepts in a clear and concise manner. Teachers must also ensure that the new concepts make sense to students. This process occurs only when teachers initially understand the students' misconceptions before addressing them. This also indicates that teachers must create conditions under which the students contend these misconceptions to create dissatisfaction. As a response, science educators have developed teaching approaches that address students' misconceptions. These includes conceptual change texts, "concept maps, concept cartoons, mind maps, and analogies" (Ozkan & Selcuk, 2012).

In addition, Fouche (2015) encourages the use of predictive questioning to ferret out students' misconceptions and address them. This requires teachers' understanding of the misconceptions and how to address them. Further, Bernhard (2000) suggested approaches that include teaching through inquiry methods such as "Peer Instruction, Real Time Physics, Tools for Scientific Thinking, and Workshop Physics". In this study, we used an approach that we termed Multi-Step Inquiry (MSI). Multi-step inquiry approach involves (1) explicit discussion of misconceptions, (2) experimentations, and (3) discussion of the conceptions for the second time, (4) misconception focused writing. Additional information regarding the MSI approach is provided under the "intervention" section of this paper. As such, in this study, we investigate the effectiveness of a MSI over traditional lecture-based teaching approach on students PSTs' conceptual understanding.

Misconceptions Studies

Figuring out misconceptions that students have prepares a way of properly addressing them. Studies show that students hold misconceptions about forces and motion, heat and temperature, and electricity that persist even after instruction. For instance, they think that forces always produce motion and therefore an object that is not moving experiences no force (Minstrell, 1982; Terry, 1985). The students further believe that for a continuous motion, there must be a continuous force acting on an object. They also believe that a constant force is needed to produce a constant speed. According to Palmer and Flanagan (1997), this confusion may arise because of the students' misunderstanding of the relationship $F = ma$. In their minds, there must always be acceleration when forces are applied. In this case, the students lack understanding of the concept of balanced forces. Atasoy, Kucuk, and Akdeniz (2011) found that PSTs had similar misconceptions as indicated above. In general, they found that PSTs thought that a continuous force is needed to keep an object going. However, the force fades away after some time and the object stops.

Misconceptions are not confined to forces and motion but also heat and temperature. For instance, Alwan (2011) found that college physics students had misconceptions about heat and temperature. Among the prevalent misconceptions are that "temperature always changes as water is heated, bubbles observed during heating water are hydrogen and oxygen, and boiling point is the maximum temperature a substance can reach" (p. 603-604). Kartal, Öztürk, and Yalvaç (2011) observed more misconceptions including "substances at higher temperature have more heat, temperature of objects in the same room depends on the type of the objects, and temperature depends on the amount of the substances" (p. 2760-2761). Preservice elementary teachers held similar misconceptions. Frederick, Van Der Valk, Leitte, and Thoren (1999) found that the PSET thought of heat as a substance such as water or air. There was confusion between hot air and heat. Further confusions arose when the PSTs tried to distinguish heat and temperature. They believed that temperature always rises as heat is applied. These misconceptions are similar to what elementary school students face. To investigate this similarity, Lee (2014) compared conceptual understanding between PSTs and fourth graders. This study found that both PSTs and the fourth graders had similar difficulties in understanding heat and temperature concepts. Lee thus proposed a method to address these misconceptions called Explore, Diagnose, Design, Discuss, Use (ED³U). This approach provides opportunities to get involved with the instructional material in an active and meaningful manner. In addition, PSTs face misconceptions in understanding both current and static electricity. Hermita, Suhandi, Syaodih, Samsudin, Isjoni, and Johan (2017) showed that PSTs had a lot of misconceptions about direct electric current, which persisted even after instruction. PSTs also had problems understanding open circuits and short circuits (Önder, Şenyiğit, & Silay, 2017). Another study (Hermita, Isjoni, Suhandi, Syaodih, E., Samsudin, and Rochman, 2017) also showed a lot of misconceptions in understanding static electricity.

As a result of these misconceptions, educators have developed various instructional approaches to alleviate the problem. Yet it is important to take note that students' misconceptions are persistent even after instructions. Therefore, not every instructional approach has been effective at resolving misconceptions. For example, a study by Bani-Salameh (2017) found that students did not significantly change their misconceptions about forces and motion after conceptual change instruction. The gain score on the Force Concept Inventory was 0.10, which is very low. The small change happened even when the authors actively taught with emphasis on conceptual understanding before quantitative problem solving.

However, other researchers observed improvements with conceptual change curriculums. For example, Clement (1993) designed lessons to deal with students' alternative conceptions in mechanics. Instructional techniques involved the use of analogies. Atasoy et al. (2011) resolved science student teachers' misconceptions of forces and motion using worksheets that encourage students to discuss and explore this topic. Fan, Geelan, and Gillies (2018) found that using interactive simulations improved understanding of physics concepts. This inquiry process required students to make predictions about the concepts and test them. Teachers guided the students' discussions to develop the right conceptions. Gok (2012) used peer instruction to improve students' conceptual understanding of forces and motion. In this method, students discussed difficult questions with peers during instruction. The study was a quasi-experimental treatment control group design, which found that the treatment group performed significantly better than the control group on Force Concept Inventory (FCI) scores.

Another approach that has shown potential in dealing with misconceptions is the use of conceptual cartoon worksheets. Taşlıdere (2013) implemented this approach to address misconceptions in direct current electric circuits. This approach resulted in a statistical difference (in favor of the experimental group) in conceptual understanding between treatment and control groups mainly because of the disequilibrium created during the discussion phase of the activities. Further, Kapartzianis and Kriek (2014) designed conceptual change activities

based on conceptual change model espoused by Posner et al. (1982) in simple electric circuits to improve conceptual students' understanding.

Method

Participants

Seventy-four (74) pre-service elementary teachers from a Northwestern USA participated in the study. Over 90 percent of the participants were females. These participants enrolled in a physical science class for pre-service elementary teachers at this college during Fall 2017, Spring 2018, Fall 2018, and Spring 2019 semesters. As a result, the sample was convenient. The participants had very little background in college science but were introduced to physical science in middle and high school. Of these participants, 39 were in the experimental group and 35 were in the control group. The treatment groups comprised Spring 2018 ($N = 20$) and Fall 2018 ($N = 23$) while the control groups comprised Fall 2017 ($N = 20$) and Spring 2019 ($N = 15$) semesters. We used several semesters to ensure a relatively larger sample for our study.

The Intervention

An inquiry module has been developed to address physical science conceptions throughout the semester. In general, the MSI approach involves (1) explicit discussion of misconceptions, (2) experimentations, and (3) discussion of the conceptions for the second time, (4) misconception focused writing. The module comprises explicit discussion of these misconceptions through group discussions and experiments. During the group discussions, students go over questions that challenge their ideas about specific concepts. Each group answers the specific questions. Then different groups present specific answers based on their understanding of specific concepts. After this, the class undertakes systematic activities that include experiments on activities such as free fall, Newton's laws of motion, boiling water activities, and momentum activities among others. In some instances, YouTube videos are used to deepen students' understanding of the concepts. Then, students, go on and discuss the concepts again after the activities. Afterwards, the whole class discusses the concepts with guidance from the instructor. At the end of each section, students write essays that address specific concepts in each section. In total, there are three essays that address, (1) forces and motion, (2) heat and temperature, (3) electricity. This multi-step process provides more opportunities for the PSTs to deal with specific concepts. The essay comprises the following:

- Select 8 misconceptions among the following and write an essay that addresses the misconceptions.
- Briefly describe why these statements are misconceptions.
- Identify the sources of these misconceptions.
- Provide the acceptable conceptions for the statements.

For example, to introduce the concept of free fall, students discussed a series of questions based on free fall in their groups. Afterwards, they were given balls of different masses to determine whether the balls touch the ground at the same or different times when dropped from the same height. Then they watched a YouTube video on free fall, followed by a demonstration of free fall from the instructor using a vacuum tube. Later, the students worked on detailed questions in their groups to check their understanding. At the end of the unit, the students wrote an essay that included several questions on free fall as shown in Table 1.

Table 1. Exemplar MSI Activity

MSI category	How it is addressed in free fall section
Pre-discussion	<ul style="list-style-type: none"> • Complete conceptual questions about free fall. • Groups present their conception to class. • Groups discuss how they can investigate different conceptions of free fall.
Experimentation/demonstration	<ul style="list-style-type: none"> • Working with balls to determine falling times. • Watching video on free fall • Observing a demonstration of free fall
Post-discussion	<ul style="list-style-type: none"> • Group and class discussions of the experiments and observations. • Revisiting pre-activity conceptual questions. • Discussing more questions prone to misconceptions in free fall in groups and as a class.
Misconception essay	<ul style="list-style-type: none"> • Inclusion of 3 questions on free fall on misconception essay 1.

Teaching in the control group involved a traditional approach which included power point presentation by the instructor, experimentations, and group discussions of lab activities and specific concepts after the presentation, and students writing individual assignments. Notable differences were that no conception essay assignments were available. Instead, students were assigned a homework activity. Further, students were not required to discuss ways to investigate their conceptions, and there were no individual group discussions of specific conceptual questions. Instead, the instructor sought understanding from the whole class through verbal questions and from individuals using a short in-class assignment. Further, this section did not use the prepared misconception module. Effort was made to ensure equal amount of contact time for both groups. Table 2 distinguishes the two instructional approaches for the two groups.

Table 2. Instructional Approaches Between Experimental and Control Classes

Activities	Control	MSI
Preview discussions	<ul style="list-style-type: none"> • Whole class check of general previous knowledge through instructor oral questioning. • The questions focus on science misconceptions. • Teacher gets answers from different students. • Teacher introduces the day's activities 	<ul style="list-style-type: none"> • Individual group discussions of explicitly written conceptual questions. • Groups presentation of their conception to the whole class • In these presentations, students provide reasons for their answers. • Groups are asked to propose investigations that can help confirm their understanding.
Experimental activities	<ul style="list-style-type: none"> • Students get involved in activities including experiments, demonstrations, or YouTube videos. 	<ul style="list-style-type: none"> • Experiments, demonstrations, or YouTube videos specifically tailored to addressing misconceptions.
Post activities	<ul style="list-style-type: none"> • Groups present their results and conclusions to the whole class • Class summarizes the findings • The teacher verbally asks questions related to important concepts from the experiment to individuals in the class. • Teacher presents a PowerPoint addressing important concepts of the lesson. • Students write a short in-class assignment that addresses the class activity and check their changes in conception. 	<ul style="list-style-type: none"> • Groups present their results and conclusions to the whole class • Class summarizes the findings • Another group discussion, revisiting the previous conceptual questions • Groups reflect on any changes to their earlier conceptions as they discuss. • Individual group discussion of added conceptual questions with teacher guidance • Whole class discussion of conceptual questions.
Essay	<ul style="list-style-type: none"> • A written individual homework assignment 	<ul style="list-style-type: none"> • Conceptual essay

One of the researchers taught both the control and treatment sections over the course of all the four semesters: Fall 2017, Spring and Fall 2018, and Spring 2019.

The Instrument

The instrument (see Appendix) in this study was self-developed after reviewing literature on students' misconceptions and going over websites that describe physical science misconceptions for elementary students. The website, <http://www.amasci.com/miscon/opphys.html>, has a very long list of children's misconceptions. This website was very helpful in developing the instrument. Using these different sources, we developed a multiple-choice test that measures students' ability to recognize the right conceptions. The instrument comprises three sections: forces and motion (11 items), heat and temperature (9 items), and electricity (11 items). The test items were constructed to ensure that each distractor item brings out students' misconceptions related to the course content. All items in the test were conceptual. We conducted construct validity to determine the clarity, relevance, and correctness of the instrument. One physicist, one physics educator and 20 pre-service elementary students were involved in this process. The two experts looked at the questions to determine the inclusiveness,

clarity, and correctness. The experts suggested necessary changes to the instrument, especially in the wording and answers of some test items. The pre-service teachers focused on clarity and understanding of the questions. The PSTs wrote on the paper under each unclear item. We then made the necessary changes based on both the experts and the PSTs. Internal reliability of the instrument was measured using split-half correlation by pairing odd and even items to obtain a strong correlation coefficient of 0.83. Using Spearman-Brown prediction formula to adjust for the full test, the correlation coefficient becomes 0.91. This shows that the instrument has good internal reliability.

Data Analysis

Data analysis involved use of both descriptive and inferential statistics. First analysis investigated conceptual changes within each semester for each of the two groups to determine gain scores. Hake's g was used to interpret the data. The next analysis involved comparison of conceptual scores between the treatment and control groups. For this analysis, a t -test assisted in determining statistical significance while Cohen's d helped with practical significance. Other analyses include comparisons between the treatment and control groups on the three sections of the instrument: forces, heat and temperature, and electricity. Descriptive statistics used include mean scores, standard deviations, and a bar chart.

Results

How Does Conceptual Understanding Change After a Semester?

Table 3 shows results of the conceptual test at the beginning and end of the semester. The control group changed their score from 7.65 to 18.37 out of 31 points. There was a significant difference between the pre- and post-tests ($p = 0.000$). Effect size calculations showed a large effect for Cohen's d ($d = 3.00$) and a medium effect size for Hake's g ($g = 0.45$). The experimental group changed its score from 8.41 to 24.10 ($p = 0.000$, $d = 4.75$). There was a high effect size based on Hake's test ($g = 0.69$).

Table 3. Gain Scores for Experimental and Control Group

Tests	Control (out of 31)	Experimental (out of 31)
Pre-test	7.65±2.71	8.41±2.71
Post-test	18.37±4.26	24.10±3.81
p	0.000	0.000
d	3.00	4.75
g	0.45	0.69

Table 4 shows the changes during the semester based on the three categories, forces and motion, heat, and electricity. Changes for both groups in all the three categories were statistically significant ($p < 0.05$). However, we observed larger changes in the treatment group as demonstrated by the higher Hake's g values.

Table 4. Changes Based on Categories

Group	Tests	# of items	Pre-test	Post-test	Hake's g
Control	Forces	11	2.06 ± 1.41	5.31 ± 1.94	0.36
	Heat	9	2.49 ± 1.15	5.86 ± 1.55	0.52
	Electricity	11	3.00 ± 1.54	7.11 ± 2.10	0.51
Treatment	Forces	11	2.16 ± 1.64	7.63 ± 1.69	0.6
	Heat	9	2.59 ± 1.30	7.38 ± 1.43	0.75
	Electricity	11	3.92 ± 1.87	8.51 ± 2.41	0.64

Comparison between Control and Experimental Groups

Table 5 shows a comparison between pre- and post-test scores between the experimental and the control groups. On the one hand, there was no significant difference observed between the control and experimental groups during the pre-test ($t = 1.19$, $p = 0.24$). On the other hand, the treatment group performed much better than the

control group in the post-test ($t = 6.61$, $p = 0.000$). There was an observed large effect size based on Cohen d 's test ($d = 1.41$)

Table 5. Comparison Between Experimental and Control Groups

Group/Tests	Pre-test (out of 31)	Post-test (out of 31)
Control	7.66±2.71	18.37±4.26
Treatment	8.41±2.71	24.10±3.81
t	1.19	6.11
p	0.24	0.000
d	-	1.41

Figure 1 shows comparisons of post-tests between the control and experimental groups across the three categories. The forces section had the largest difference followed by the heat section. Differences in all the categories were statistically significant ($p < 0.05$).

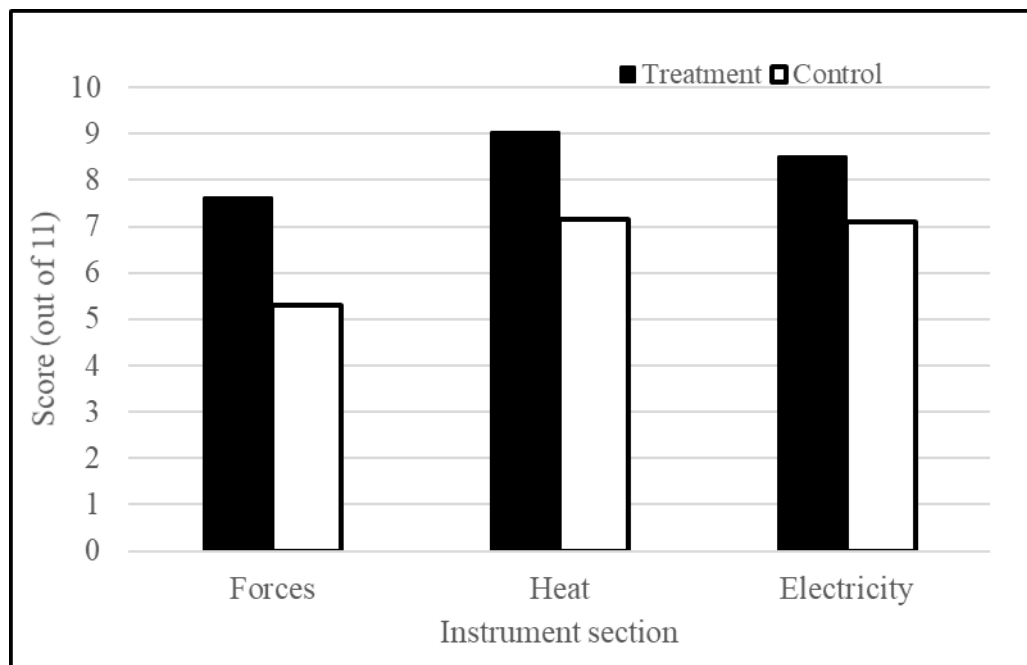


Figure 1. Comparisons based on Conceptual Test Categories

Discussion

A look at the pre-tests for the treatment and control groups shows very low scores in physical science conceptual understanding. This is a worrisome outcome because these PSTs are at college level where they are expected to understand misconceptions held by elementary students. The preconceptual scores have also confirmed that PSTs hold the same misconceptions that elementary school students have (Asoko, 2002a; Heywood, 2007; Schoon, K. J., Boon, 1998; Trundle, K. C. Atwood, R. K., & Christopher, 2007; Webb, 1992). This provides a justification for developing a curriculum that addresses these misconceptions. Results for the control section shows a statistical difference between the pre- and post-tests scores. Further, Cohen's d values (Cohen, 1960) indicate a large effect size. However, a further analysis using Hake's g indicates a medium effect size of 0.45. This is unsurprising because the control group also had some active learning. Hake (1998a) found that the average g for classes that involve active learning is above 0.3. Based on Hake's effect size, the control group experienced a lower gain in relation to the treatment group ($g = 0.7$). Cohen's d values indicate that the learning gains for the experimental group were not only statistically significant but also practically significant.

When compared with the control group, the treatment section performed statistically better ($t = 7.78$, $p = 0.000$). The Cohen's d of this difference is 1.41, indicating that the effectiveness of MSI is substantial. In simpler terms, the two means differ by a whole standard deviation. Students' misconceptions are recalcitrant and thus need effective approaches to addressing them (Prince, Vigeant, & Nottis, 2016; Schmidt, 1997). Specifically, students who are in college have had these misconceptions for a long time, which makes it even more difficult to deal

with. Traditional physics instruction will not effectively knock down these misconceptions. We believe that the instruction in this class was effective because of its multistep approach. Students had several opportunities to explicitly deal with similar concepts in different formats. This likely effectively embedded these right conceptions in their minds. Posner et al.'s (1982) proposal about dealing with misconceptions shows the rigorous nature of the work needed to address them. The MSI provided students with an opportunity to display their initial conceptions, presented situations which caused disequilibrium, and provided enough resources to ensure that students were satisfied with their new conceptions. This probably created disequilibrium (Posner et al., 1982; Taşlıdere, 2013) in students during class discussions and also during information search as they wrote misconception essays. The control group lacked these opportunities and thus has lower scores. Results from this study align with findings from various researchers who found improved conceptual understanding after using various conceptual change curriculums (Atasoy et al., 2011; Clement, 1993; Gok, 2012). These researchers and our study attribute this success to student teachers' active participation in the learning process and careful and explicit processes that required students to acknowledge their misconceptions and conduct activities to address these misconceptions. Specifically, the essay activities enabled the student teachers to take charge of their own learning process, which likely stimulated learning. In addition, the MSI provided enough opportunities for the students to interact with the concepts further cementing understanding.

Recommendations

This research has shown that science educators have a task to find out and effectively address misconceptions in student teachers. Knowing PSETs misconceptions is a good starting point to addressing them. This study has shown that a multi-step approach has potential to provide necessary experiences that can effectively change students' misconceptions. As such, this study provides a pathway that can assist science educators in their preparations of prospective elementary science teachers. Further, the instrument used in this study can be used to obtain both baseline and post instructional conceptual understanding from students in various physical science courses. The strength of the instrument is the ability to capture concepts from different physical science topics. As such, the instrument is well suited for physical science courses.

Limitations

The course under which this research took place has a maximum of 24 students. As such, the research occurred within a span of four semesters to allow a relatively larger sample size. However, great care was taken to ensure that the students in these different semesters are given similar experiences based on their group: treatment or control.

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Appendix. Physical Science Concept Survey

This paper contains 31 multiple-choice questions. Answer all the questions on the scantron sheet.

Section 1: Forces and Motion

1. The speed of an object is increasing. What can be said about an object's acceleration, if any?
 - (a) Increased acceleration
 - (b) Constant acceleration
 - (c) No acceleration
 - (d) We need more information
2. An object is at rest. We can assume that
 - (a) Some forces are acting on it.
 - (b) No forces are acting on it.
 - (c) The only force acting on this object is gravitational force.
 - (d) Two forces are acting on it: air resistance and gravitational force.
3. An object is moving towards the north on a horizontal surface. There is a horizontal force acting on it. What does this mean?
 - (a) We can conclude that the force is acting southward.
 - (b) We can conclude that the force is acting northward (in the direction of motion).
 - (c) Force will be used up in the long run. So, direction is irrelevant.
 - (d) We need more information to tell the direction of the force.
4. An aircraft has a constant speed of 450 mi/h for 2 hours in the same direction and altitude. This means that the aircraft
 - (a) Has a constant force propelling it.
 - (b) Has a constant acceleration.
 - (c) Has no forces acting on it.
 - (d) Has balanced forces acting on it.
5. When Stephanie pushed a trolley on a certain surface, the trolley stopped after some seconds. From this observation, we can conclude that
 - (a) An object that is in motion will always come to a stop.
 - (b) Once the force from Stephanie was used up, the object had no more force to continue.
 - (c) The trolley was supposed to keep on moving.
 - (d) Both (a) and (b) are correct.
 - (e) None of the above.
6. Dan applied a force on an object. From what he did, we can conclude that the object
 - (a) Moved toward the direction of the force.
 - (b) Stayed stationary
 - (c) Increased in speed as he kept pushing.
 - (d) Both (a) and (c) are correct.
 - (e) We need more information to answer this question.
7. I threw a rock in a horizontal projectile fashion. When the rock left my hand, it travelled for 10 meters before starting to fall. After some distance, the rock fell to the ground. What conclusion can we make from this observation?
 - (a) There was a horizontal force pushing the rock all the way to just before 10 m distance.
 - (b) After the rock left my hand, it no longer experienced a horizontal force.
 - (c) After the rock left my hand, it experienced both horizontal and gravitational force.
 - (d) After the rock left my hand, it no longer experienced any kind of force.
 - (e) None of the above.
8. Dora pushed a cart for 10 meters on a frictionless horizontal surface. The cart has well lubricated wheels such that friction can be ignored. Air resistance is small and can be ignored as well. After 10 minutes, she lets go of the cart. Select a correct statement below.
 - (a) Since Dora has stopped exerting force, the cart will stop after some time.
 - (b) The cart will not stop unless it hits an obstacle
 - (c) The cart is still experiencing a force from Dora although she let it go, thus it will keep on moving steadily.
 - (d) The cart will stop immediately after Dora lets it go.
 - (e) We need more information to answer this question.

9. Two vehicles, a large truck and a small sedan had a head on collision on a countryside road. The road had no signposts showing the miles per hour such that drivers' speed depended on their discretion. What statement can we deduce from this information?
- Both vehicles hit each other with the same amount of force.
 - The large truck exerted a larger amount of force than the small sedan.
 - The small sedan exerted a larger amount of force than the large truck.
 - It is difficult to know which vehicle had exerted force during the impact from the information presented.
 - None of the above.
10. A spaceship floated in space for 2 years with its engine off. During this time, the spaceship
- Had zero gravity.
 - Was acted upon by gravitational force.
 - Had no force acting on it.
 - Had zero velocity.
 - None of the above.
11. Astronauts can easily float in a spaceship because
- There is zero gravitational force in space.
 - Their suits are made of floating material.
 - The only force acting on both astronauts and the ship is gravitational force.
 - They have zero velocity in space.
 - All of the above.

Section 2: Heat and Temperature

12. The highest temperature that water can reach is
- Greater than 100 °C.
 - Less than 100 °C.
 - 100 °C.
 - We need more information.
 - None of the above.
13. Joana told her friend that as she was heating up water, she observed that at one point, there was no temperature change although she kept on heating the water. What can best explain this observation?
- This is possible because temperature does not change as the water is boiling.
 - The hot plate malfunctioned during the heating process and thus could not heat up the water.
 - This is not possible because as you add heat, temperature always increases.
 - The temperature reached the maximum point of the thermometer.
 - The thermometer malfunctioned.
14. Salt is put on the roads during winter because salt
- Provides heat to melt the ice.
 - Decreases the melting point of ice.
 - Increases the melting point of ice.
 - Only (b) and (c).
 - Only (a) and (b).
15. John observed bubbles as he heated water to 35 °C way before the boiling point of 100 °C. Where did these bubbles come from?
- Water vapor.
 - Oxygen.
 - Air escaping from the water due to heat.
 - Water vapor and oxygen.
 - Nitrogen.
16. How do you compare the internal energy (heat) of a very huge iceberg, which is at -15 °C, to that of a small cup of boiling water, which is at 100 °C?
- The cup of boiling water has more internal energy than the iceberg
 - Iceberg will have the same internal energy with a cup of water only when they are at the same temperature.
 - The iceberg has more internal energy than a cup of boiling water.
 - Only (b) and (c).
 - Only (a) and (c).

17. Students were asked to touch a metal box and a book under the same conditions (in the same room) in winter. The hand felt warmer when touching the book than when touching the metal box. If these two objects have stayed in this room for at least **two** days, which of the statements below is true?
- The book had more heat than the metal.
 - The book transferred heat more easily than the metal.
 - The book was at a higher temperature than the metal.
 - Both the book and the metal box were at the same temperature.
 - Only (a), (b) and (c).
18. I put a metal spoon, a plastic spoon, and a wooden spoon in boiling water and wait for 2 hours. If the boiling point of water is $100\text{ }^{\circ}\text{C}$, what will be the temperature of the spoons after 2 hours?
- All of them will have a temperature of $100\text{ }^{\circ}\text{C}$.
 - Only the metal spoon will be at $100\text{ }^{\circ}\text{C}$ but the plastic and wooden spoons will be at lower temperature.
 - We can't know their temperatures without measuring each spoon.
 - The wooden spoon will have the lowest temperature.
 - The plastic spoon will have the lowest temperature.
19. During winter, in a heated house, the temperature of the glass window is usually lower than the temperature of objects in the house. Explain this observation.
- Coldness is transferred from outside into the room through the window.
 - Coldness is pushed out of the room by heat through the window.
 - The temperature of the window is influenced by the outside temperature more than the other objects in the room.
 - The temperature of the glass window is always equal to the temperature of other objects in the house.
 - Only (c) and (d).
20. In winter, students conducted an experiment, where they put one ice block on a plastic block and one ice block on an aluminum block, under the same condition, to see which of the two blocks melt the ice more quickly. The plastic block was initially warmer to touch than the aluminum block. What do you expect to happen?
- The aluminum block melts the ice more quickly than the plastic block.
 - The plastic block melts the ice more quickly than the aluminum block.
 - The ice will melt at the same rate on both blocks.
 - We need more information to answer this question.
 - None of the above.

Section 3: Electricity

21. Jane and Jill argued about electric current. While Jane believed that electric current is exclusively due to electrons, Jill felt that there may be other particles apart from electrons. Who is right?
- Jane, because electric current involves movement of electrons only.
 - Jane because you need wires to have electric current and wires contain electrons.
 - Jill because protons can also carry charges.
 - Only (a) and (b).
 - None of the above.
22. What is the role of an electrochemical cell in a complete (closed) circuit?
- It is a source of charge.
 - It acts as a pump to provide direction to the charges in the wires in the circuit.
 - It adds more charges to the wire in the circuit
 - Both (a) and (b).
 - Both (b) and (c).
23. After one week of use, an electrochemical cell (battery) could no longer light a bulb. What might be a reason for this observation?
- The chemical reactions within the electrochemical cell had completed.
 - The wire had used up all the charges it received from the cell.
 - The charge within the electrochemical cell had been used up.
 - None of the above.
 - All of the above
24. In a certain series electrical circuit, 0.75 A of current (related to charge flow) enters the light bulb. How much current will leave the light bulb back to the electrochemical cell?

- (a) It will be slightly less than 0.75 A because the bulb has used up some current.
 - (b) It will be slightly greater than 0.75 A because the light bulb has added some charge to the wire.
 - (c) It will be equal to 0.75 A because the bulb does not use up nor add charge.
 - (d) We need more information to answer this question.
 - (e) None of the above.
25. When Tom turned the switch on, immediately the bulb lit up. How do we explain this observation?
- (a) Charge flows through the circuit at the speed of light.
 - (b) Although a single electron may travel slowly, many electrons travel extremely fast.
 - (c) The electric field responsible for an electrical signal travels close to the speed of light.
 - (d) All of the above.
 - (e) None of the above.
26. When a student added a portable battery to complete a circuit, a lightbulb lit up. This is possible because
- (a) The portable battery provided electrons to light the bulb.
 - (b) Electrons from the portable battery moved into a hollow wire to light the bulb like water moves into a hollow water pipe.
 - (c) The portable battery enabled electrons to move from atom to atom.
 - (d) The portable battery provided a net direction for charges.
 - (e) None of the above.
27. When you remove an electrochemical cell from a complete circuit and reconnect the wires without the cell, the bulb does not light up. This observation is likely due to the fact that:
- (a) Since the cell provides charge, removing it stops the bulb from lighting.
 - (b) The electrons in the wires stop moving and thus cannot light the bulb.
 - (c) When the cell is removed, the electrons do not have a net direction thus cannot light bulb.
 - (d) Only (a) and (b).
 - (e) Only (a) and (c).
28. When you connect a dry cell (electrochemical cell) or a battery to complete an electrical circuit, the following happens:
- (a) Current circulate throughout the circuit including inside the cell or battery.
 - (b) Current leaves one side of the battery and ends on the other side of the cell or battery.
 - (c) When a dry cell is connected to the circuit, current circulates throughout the circuit including the cell. When a battery (e.g. car battery) is used, current moves from one end of the battery and ends up at the other end.
 - (d) When a battery is connected to the circuit, current circulates throughout the circuit including the battery. When a dry cell is used, current moves from one end of the cell and ends up at the other end.
 - (e) None of the above.
29. Static electricity can be best described using the statement below.
- (a) It involves particles that are stationary.
 - (b) It involves separation of positive and negative charges.
 - (c) It involves nonmetals only.
 - (d) It involves metals only.
 - (e) Nonmetals always receive electrons.
30. Static electricity can be best described using the statement below.
- (a) It involves particles that are stationary
 - (b) It involves separation of charges
 - (c) It involves only nonmetals
 - (d) Metals experience more static electricity than nonmetals
 - (e) Nonmetals always receive electrons.
31. We can describe static electricity as always
- (a) A result of friction.
 - (b) Electricity at very low voltage.
 - (c) Weak and feeble.
 - (d) Caused by imbalance of charges.
 - (e) Affecting nonmetals.