Scientific Research Publishing

Creative Education, 2024, 15, 2131-2150
https://www.scirp.org/journal/ce
ISSN Online: 2151-4771
ISSN Print: 2151-4755

Strengthening Elementary Preservice Teacher Content Knowledge in Science through Model Based Inquiry

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How to cite this paper: Nollmeyer, G. E., & Baldwin, K. A. (2024). Strengthening Elementary Preservice Teacher Content Knowledge in Science through Model Based Inquiry. *Creative Education, 15,* 2131-2150.
https://doi.org/10.4236/ce.2024.1510131

Received: September 21, 2024
Accepted: October 25, 2024
Published: October 28, 2024

Abstract

Science methods classes are charged with teaching preservice teachers how to teach science (PCK); however, since the ability to teach science is limited by the depth of understanding about what is being taught (CK), there is a tension for science teacher educators to negotiate. In this study we explore the possibility of advancing preservice elementary science teachers CK through an authentic science investigation experience using instructional methods that should develop their PCK as well. Analysis of the data revealed that growth in preservice teachers' CK was statistically significant for each of the four quarters. In addition, most participants who held misconceptions in the pre-assessment no longer demonstrated these in the post-assessment.

Keywords

Elementary Teacher Preparation, Science Education, Science Teacher Education, Content Knowledge

1. Introduction

Undergraduates pursuing a degree in elementary education typically enter a teacher program during their junior year of college. During their first two years of school, they have completed general university requirements and the prerequisites for the teacher program. This includes a certain number of science content courses. It is assumed that these courses will prepare the preservice teachers with the science content knowledge (CK) needed to teach elementary science. Unfortunately, elementary teachers often lack sufficient CK (Sorge et al., 2019). This should create a sense of urgency for science teacher educators (Santau et al., 2014) to work creatively in support of these young teachers. Once in the teacher program, the focus shifts from content and foundation courses to methods courses—at least in the discipline of science. Elementary teacher programs will almost always include one (but rarely more) science methods course. The purpose of a methods course is to develop pedagogical content knowledge (PCK)—teaching students the best pedagogical practices associated with a particular discipline. Since preservice teachers lack the necessary science CK, one of the distinct challenges of planning a science methods course for future elementary teachers is striking the perfect balance between the necessary focus of the methods of science teaching (PCK) and the ever-present need for strengthening science CK. Santau et al. (2014) challenge science teacher educators to refocus on CK in methods courses. After all, weak CK limits the development of PCK (Baumert et al., 2010; Davis, 2004; Santau et al., 2014). Still, the correct balance is difficult because there is never enough time to teach all that we would like to teach. Even with science CK concerns a reality, methods instructors must emphasis PCK because elementary teachers often have a deficit here as well (Roehrig & Luft, 2004).

An added burden in our program is the fact that we are on the quarter system. With only 10 weeks of instruction instead of the 16 weeks of a semester course, careful and creative planning in our methods course is even more essential. One way we approach this issue is to make sure we are constantly engaging students in authentic science experiences while modeling the methods of inquiry. Preservice teachers' CK and PCK can both be developed through authentic science inquiry experiences (Correia & Baptista, 2022; Gillies & Nichols, 2015). We situate these investigations in the various disciplines of science so that students are exposed to multiple science concepts through the very methods we hope they employ while teaching. Anecdotally, during these investigations, we frequently notice that students either hold misconceptions about the science content or at least lack confidence in the content.

The purpose of this study was to learn how our use of authentic science inquiry experiences intended to impart sound PCK might also develop preservice teacher CK. One of the pedagogical frameworks we introduce to the preservice teachers is Model-Based Inquiry (MBI). We use MBI while investigating the challenging science concept of buoyancy. Since MBI encourages repeated model development and editing, collecting student buoyancy models before and after the investigation allows us to evaluate concept development. Two questions served to guide this research.

i) How effective and consistent is MBI in helping preservice teachers deepen their CK of buoyancy?

ii) What misconceptions do preservice teachers have about buoyancy before and after the MBI lesson sequence?

2. Literature

2.1. PCK Framework

Nearly forty years have past since Shulman (1986) first proposed his now ubiquitous framework for teacher knowledge. Though his initial categorization (Shulman, 1986, 1987) was more complex and fluid, he recognized at the time, "Among those categories, pedagogical content knowledge is of special interest because it identifies the distinctive bodies of knowledge for teaching" (Shulman, 1987: p. 8). PCK has indeed been of special interest ever since. Magnusson et al. (1999) refer to its identification as revolutionary. Since that time, many researchers have worked to fully conceptualize it (e.g. Gess-Newsome, 1999; Hashweh, 2005; Kind, 2009; Van Driel et al., 1998). Others have studied its impact on teaching and learning (e.g. Baumert et al., 2010; Buczynski & Hansen, 2010; Cauet et al., 2018; Hill et al., 2005). However, while PCK has become the widely recognized standard for science teacher professional knowledge and effectiveness (Leuchter, et al., 2020), there still is no consensus on what PCK actually means (Neumann et al., 2019). In the current study, we view PCK as transformative which was initially proposed by Shulman and his colleagues (Shulman, 1986; 1987; Wilson & Wineburg, 1988) and a perspective shared by other researchers (Berry et al., 2008; Magnusson et al., 1999; Nilsson, 2008; van Driel et al., 1998). This means that PCK is a separate kind of knowledge (Neumann et al., 2019) drawn from various domains (Magnusson et al., 1999). It is the knowledge of how to teach specific topics within a discipline (Kulgemeyer & Riese, 2018) so that it is accessible to specific students (Neumann et al., 2019). Thoughts from multiple domains of knowledge come together to form an amalgam (Shulman, 1986) that is more than the sum of its parts.

As conceptualizations of PCK have been developed, advanced, and tested, researchers have also studied teachers' CK and the relationship, if any, between CK and PCK (e.g. Correia & Baptista, 2022; Fischer et al., 2014; Hill et al., 2005; Kulgemeyer & Riese, 2018). Even secondary science teachers whose only concentration is either broad or single science discipline teaching, have a disjointed and limited CK (Lederman & Chang, 1997). This issue is more significant for elementary teachers. Khourey-Bowers and Fenk (2009) report that after a professional development experience elementary teachers' science CK was still lower than the secondary science teachers' CK at the beginning of the training. This should not be a surprise. Elementary teachers have far fewer structured opportunities to grow in their science CK as compared with secondary science teachers. After all, elementary teachers must take courses to prepare them for teaching multiple disciplines including literacy, mathematics, social studies, science, and more. Banilower et al., (2013) found that less than half of elementary teachers take a college course in chemistry or physics. Roughly 90% of high school science teachers take at least one in each. Even for the elementary teachers who have taken a course in these disciplines, it will almost always be at the introductory level. On the contrary, many secondary science teachers will have multiple, higher level, courses in each discipline. Regardless, the science content courses college students complete often do not lead to deep learning and conceptual change (Khourey-Bowers & Fenk, 2009). This means that many strongly held misconceptions developed in youth remain for preservice teachers even after the successful completion of a teacher preparation program (Lederman & Chang, 1997). Preservice teachers' limited CK is of critical importance since a teacher's CK is always a limiting factor in the advancement of their PCK (Baumert et al., 2010). A teacher's CK influences instructional decisions; those with stronger CK are more likely to plan for authentic inquiry experiences for students (Davis, 2004; Santau et al., 2014). In addition, a deeper understanding of a science concept leads to greater ability to provide rich and effective learning experiences for students (Khourey-Bowers & Fenk, 2009).

Sufficient PCK requires teachers to go beyond merely understanding content. A teacher's PCK requires the ability to perceive the most effective "ways of representing and formulating the subject that make it comprehensible to others" (Shulman, 1986: p. 9). Therefore, CK must be deep and conceptual, yet adequate PCK is an even larger concern. Kulgemeyer and Riese (2018) found that while both CK and PCK were important in a teacher's ability to explain science concepts, it was the PCK that really made the explanation possible. Elementary teachers with a stronger PCK can provide more advanced scaffolding techniques to promote student learning (Leuchter et al., 2020). Unfortunately, opportunities for developing elementary preservice teachers PCK in science are limited. Since there is overwhelming focus on literacy and mathematics, preservice teachers' placement experiences rarely model rich authentic science inquiry (Heywood, 2007). This makes the science methods course all the more important. In spite of these challenges, research has shown that science methods courses can indeed produce growth in both CK and PCK (Correia & Baptista, 2022; Santau et al., 2014; Smit et al., 2017).

2.2. Model Based Inquiry

MBI, as popularized by Windschitl et al. (2008), was a response to pervasive use of The Scientific Method. Since scientific knowledge is testable, revisable, explanatory, conjectural, and generative, Windschitl's et al. (2008) framework for MBI was designed to ensure that students would interact with science via this epistemology. Over the following ten years, the team studied and developed the model into published form—Ambitious Science Teaching (AST) (Windschitl et al., 2018). Traditional classroom methods present a simplistic science where knowledge is fixed and merely disseminated to students (Duschl et al., 2007). These lectures and readings might be followed by "cookbook labs" lacking authenticity (Rinehart et al., 2016). These labs typically use the rigid steps of The Scientific Method. Such pedagogies fail to meet the intellectual requirements for any of the five epistemic aspects of scientific knowledge (Windschitl et al., 2008).

Over a century ago, Dewey (1910) proposed a broad, flexible structure for science in the classroom in an attempt to bring authenticity to school science. This quickly became known as The Scientific Method. Unfortunately, within a decade, his proposal had become a simplistic, linear, ridged procedure that was a close facsimile to the very stilted school science he had written against (Rudolph, 2005). Regardless of attempts by science educators and researchers, including Dewey

(1933) himself, to rid the classroom of The Scientific Method, it remains the central perspective of science for the general population and even many science teachers (Windschitl et al., 2008). Further discussion of The Scientific Method is beyond the scope of this article. Please see (Rudolph, 2005; Windschitl et al., 2008) for a thorough review of the history of and issues with The Scientific Method. It is against this cultural background of school science that Windschitl et al. (2008) developed their framework for MBI.

Planning science classroom investigations around models and modeling is an excellent way to engage students in core practices of science. Models have become a central aspect of many scientists' work because advancements in technology have made models both accessible and powerful (Schwarz & White, 2005). Since models go hand in hand with explanation (Windschitl et al., 2018), they give power to scientific ideas and facilitate argumentation (Lehrer & Schauble, 2005). Plus, models place limits on the system under investigation which allows for needed simplifications to meet student levels of understanding (Rinehart et al., 2016; Windschitl et al., 2018). "The general aim of modeling is to test an idea—represented as a system of related processes, events, or structures—against observations in the real world and to assess the adequacy of the representation (i.e., model) against standards of evidence" (Windschitl et al., 2008: p. 944). Such inquiry makes it possible for school science to align with the five epistemological features of science knowledge: testable, revisable, explanatory, conjectural, and generative. Students thus engaged will need to use the practices of science that scientists themselves employ (Rinehart et al., 2016) which meets the expectations of the Next Generation Science Standards (NGSS) (NRC, 2012).

Instead of testing predictions that are often guesses about variables, MBI tests ideas from students' explanatory models of a phenomenon. Instead of merely drawing conclusions patterns in the data, MBI uses observable patterns along with other sources to form explanatory and conjectural edits to their models. This almost always requires going beyond what is observable in proposing ideas in the model based on unobservable processes or structures (Windschitl et al., 2008). Therefore, MBI approaches to science in the classroom are challenging and require advanced PCK. A major appeal of The Scientific Method is its simplicity for students to memorize and teachers to follow (Rudolph, 2005). MBI on the other hand is "ambitious" teaching (Windschitl et al., 2018). Authentic science teaching is always challenging (Rinehart et al., 2016). MBI specifically requires long-term effort to fully create learning environments where MBI can be successfully applied (Lehrer & Schauble, 2005). Windschitl et al. (2008) found that preservice teachers quickly slide back into simplistic content-poor instructional decisions even when trying to produce plans for MBI. This was because it was all they knew from their own experience in science classrooms. Some researchers have attempted to mediate these challenges and facilitate teacher growth in PCK as well as provide MBI experiences for students by designing curricular units (e.g. Baek et al., 2011;

Rinehart et al., 2016; Schwarz & White, 2005) or modeling tools (e.g. Brady et al., 2015). Others, like Windschitl et al. (2008; 2018) with Ambitious Science Teaching (AST), have focused on developing specific instructional frameworks for teachers to use in developing their own curriculum.

AST is a MBI instructional framework that empowers teachers to plan for authentic inquiry in the classroom (Windschitl et al., 2018). The goal is for students to produce defensible explanations for how the world works (Windschitl et al., 2008). Therefore, instead of planning for students to learn about a "topic," AST educators build investigative units centered on real-world events, processes, or phenomena (Windschitl et al., 2018). This aligns with the NGSS expectation for teaching big/core ideas situated in real-world contexts (NRC, 2012). Starting then with the anchoring event (Windschitl et al., 2018), students develop pictorial models of the real-world phenomena. The emphasis here is placed on explanation and conjecture about unobservable elements (Windschitl et al., 2008; 2018). Templates are often used to facilitate student modeling as well as the "before, during, after" approach (Fowler et al., 2020). Aspects of student models and the hypotheses they present are then tested. The evidence gathered as well as discussion and further interpretation of unobservable causes lead individuals and groups to edit their models of the phenomenon (Windschitl et al., 2008; 2018). Schooling can develop the idea that once work has been done, it is in its final form; this causes students to balk at editing. One strategy to help students break out and embrace the revisable nature of science is use sticky-notes of various colors to note model edits. Students can even do this on peer models once they learn how to make effective suggestions (Windschitl et al., 2018). Throughout, there is a strong emphasis placed on collaboration between students in this process as they develop models together, share and test ideas proposed by individuals or groups, and engaging in argumentation and collective editing (Fowler et al., 2020; Windschitl et al., 2018).

3. Methods

In the science methods course for elementary teachers, we attempt to build both science CK and PCK through content rich science investigations that employ the very frameworks for authentic science inquiry we hope our preservice teachers go use in their own classrooms. One of the instructional frameworks we introduce them to is MBI. Our view of MBI is most influenced by Windschitl's et al. (2018) AST. Using a MBI framework, we have our preservice teachers investigate buoyancy through the real-world phenomenon of giant ocean-going cargo ships. How is it possible for cargo ships like the MSC Irina (1312 feet long by 201 feet wide, with a deadweight of 240,000 DWT and a capacity of 24,346 TEUs) to float instead of sink? How can we explain it?

Though our exact process with each class varies according to initial student models (Windschitl et al., 2008, 2018), we always proceed through the same overarching phases. After a brief introduction to the phenomenon, students design their initial pictorial models. Next, we move into the investigation phase where we are putting hypotheses to the test. We pause after some investigation to edit initial models. Then, we go back to investigation. At the end, we come back and, starting with a fresh page, students design their final models.

3.1. Study Design

This quasi-experimental study was conducted at a regional university in the Pacific Northwest. The participants were preservice elementary teachers enrolled in the science methods course required for the teaching program. Data were collected for four quarters. Three of the quarters only had one section of the class. In one quarter, there were two sections. The same instructor taught each class. The students were all preservice teachers pursuing their elementary education degrees. Participation in the study and the data collected occurred within the scope of the course; students did not need to do anything outside of the class to participate. 82 students were enrolled in the methods course over these four quarters. Most chose to participate, N = 72. Only some student data was complete enough to be used in the analysis, N = 51. Students who missed part of the investigation sequence or did not submit either a pre or post model were excluded.

Data used for the study consisted of minimal demographic data associated with the course as well as student work samples collected at the beginning and end of the study. Demographic data included only course grade and quarter enrolled. The course work collected were the pre and post investigation models developed by students. Student models of the phenomenon were analyzed using the Buoyancy Rubric (see **Appendix A**). Models were scored using the Buoyancy Rubric. These data were analyzed along with demographic data to answer research questions. Descriptive statistics were performed to determine the stability of the data. Next, paired-samples t-tests were used to identify statistically significant changes in pre and post model scores. A one-way ANOVA was used to determine statistical differences between the quarters. Finally, a linear multiple regression was conducted to identify variables that best predicted participant post model scores.

3.2. RQ1

In this article our focus in on how preservice teachers' CK might develop through an authentic science investigation in a science methods course. Two questions were used to frame the study. First, we wondered how effective and consistent is MBI in helping preservice teachers deepen their CK of buoyancy? This question is of particular importance for a couple of reasons. Authentic science investigations used during science methods courses have demonstrated the ability to improve preservice teachers CK (e.g. Correia & Baptista, 2022; Santau et al., 2014; Smit et al., 2017). Science designed with the MBI framework will provide authentic experiences meeting all five epistemological features of science knowledge (Windschitl et al., 2008) and the practices of science (Rinehart et al., 2016).

Therefore, we would expect to see preservice teacher CK of buoyancy grow as a result of participating in the MBI lesson sequence. This first research question is also of interest because MBI is a flexible framework for designing inquiry experiences for students. The processes followed for a particular investigation will vary from class to class. Students' models and the hypotheses presented dictate the direction of investigation (Windschitl et al., 2008R46). While our particular MBI planning does include more of a guided inquiry structure than AST, there is still flexibility. From quarter to quarter the investigation changed in some ways to match student ideas. Therefore, we wondered if these changes might result in quarters where students had more or less growth in their CK.

In order to answer this question, student models were collected. Both pre-investigation models developed at the beginning of the investigation and post-investigation models developed at the end were collected and scored. Paired-samples t-tests were run to determine if there was significance to the differences in the pre and post scores for all quarters as well as individual quarters. Next, a one-way ANOVA was conducted to determine if there was significance to the differences in post scores between the quarters. Finally, a linear multiple regression was conducted to determine the strength of a predictive model.

3.3. RQ2

The second question used to frame the study asked what misconceptions do preservice teachers have about buoyancy before and after the MBI lesson sequence? While related to the first question, a specific focus on the difficult but essential work of teaching for conceptual change is important. Since research has demonstrated that educators can successfully complete teacher preparation programs while still retaining misconceptions about science (Khourey-Bowers & Fenk, 2009), we desired to understand the misconceptions that appeared in our preservice teachers' models at the beginning of the investigation as well as which of those remained at the end of the investigation.

In order to answer this question, pre and post student models were evaluated again. This time, the researchers were looking for the presence of misconceptions. This process was similar to qualitative analysis coding methods. A lengthy list of misconceptions was created. Student models were considered multiple times as the list was compiled and edited. Finally, the many examples of misconception were organized and categorized. Graphs were then created to provide a visual answer to the research question.

4. Results

Preservice teachers enrolled in the elementary science methods course over a period of four quarters were given the option of participating in the study. The one quarter with two sections of the class had considerably more participants. **Table 1** presents student counts for pre and post model scores as well as overall course grade counts.

Table 1. Student score & grade counts by quarter.

	Score	Quarter 1 (N = 6)	Quarter 2 (N = 22)	Quarter 3 (N = 12)	Quarter 4 (N = 11)
Pre Score	0	1	8	5	3
	1	2	4	4	6
	2	1	8	1	1
	3	2	1	2	1
	4	0	1	0	0
Post Score	2	0	0	1	0
	3	0	2	1	1
	4	1	3	2	1
	5	0	4	2	3
	6	1	5	1	2
	7	0	5	2	1
	8	2	3	3	0
	9	2	0	0	2
	12	0	0	0	1
Course Grade	87	1	0	0	0
	89	0	1	2	0
	90	0	1	1	0
	91	0	1	0	0
	92	0	1	1	3
	93	0	4	3	2
	94	1	5	2	2
	95	0	3	2	1
	96	1	3	1	0
	97	2	3	0	1
	98	0	0	0	2
	99	1	0	0	0

4.1. RQ1

The pre-investigation model scores were compared with the post investigation model scores using a paired-samples t-test. The results from the pre-investigation (M = 1.18, SD = 1.09) and post-investigation (M = 6.06, SD = 2.00) model scores indicated that participation in the MBI lesson sequence had a positive impact on preservice teachers' CK of buoyancy concepts, t(50) = 19.66, p = 0.000, d = 2.75. Next, paired-samples t-tests were run to compare mean scores within each quarter. All four tests returned significant scores (see Table 2).

Table 2. Paired-samples *t*-tests by quarter.

Quarter	Pre Mean	SD	Post Mean	SD	*t* Value	df	P Value	Cohen's *d*
1	1.67	1.21	7.33	1.97	8.50	5	0.000	3.47
2	1.23	1.15	5.77	1.54	15.56	21	0.000	3.32
3	1.00	1.13	5.58	2.07	8.23	11	0.000	2.38
4	1.00	0.894	6.45	2.62	7.88	10	0.000	2.38

Model scores were compared between the quarters: pre scores, post scores, and growth scores. A one-way ANOVA revealed differences in the pre scores from the four quarters were not statistically significant, F(3, 47) = 0.607, p = 0.614. A one-way ANOVA revealed differences in the post scores from the four quarters were not statistically significant, F(3, 47) = 1.36, p = 0.268. A one-way ANOVA revealed differences in the growth scores from the four quarters were not statistically significant, F(3, 47) = 1.16, p = 0.334.

Using linear multiple regression, we tested a predictor model to determine how effectively student post scores could be predicted by quarter, course grade, and pre-investigation model score. This resulted in a significant model, F(3, 47) = 6.64, p = 0.001, R2 = 0.253. The individual predictors were examined further and indicated that course grade (t = 2.24, p = 0.03) and pre-investigation model score (t = 3.52, p = 0.001) were significant predictors but, quarter was not (t = 0.399, p = 0.691).

4.2. RQ2

Student pre-investigation models were analyzed to determine the presence of misconceptions about buoyancy and the phenomenon under investigation: massive cargo ships made of steel and carrying thousands of tons of cargo yet still floating. Fifteen misconceptions were identified and then categorized into three areas (See **Table 3**). Seven misconceptions were grouped as misconceptions about water and its role in floating ships. Two misconceptions were grouped as misconceptions about air and its role in floating ships. Finally, six misconceptions were grouped as misconceptions about ships and their role in floating. Some misconceptions were not complete misconceptions in and of themselves but rather misapplied for the phenomenon.

Two misconceptions were clearly the most pervasive in student models. The most common misconception was about an air chamber at the bottom of the boat. Nineteen students shared some version of this misconception. A number of students identified ships as having less density than water because of air inside. However, it was very common that models showed this air at the bottom of the ship like a floatation device. During the one quarter where we used a template as a starting point for student models, several students saw evidence for this "trapped air" idea in lines on the drawing (**Figure 1**).

Table 3. Misconceptions present in pre-investigation models.

	Misconceptions	Preservice Teachers
Water	Ocean mass or volume helps ships float.	1
	Warm water rising in the ocean is part of the force keeping the ship floating.	1
	Breaking the surface tension of the water allows the weight of the ship to be distributed over a larger area.	1
	Floating ships are an example of the Bernoulli Principle.	1
	Different temperatures in the layers of water play some role in the ships floating. (e.g. Denser objects attracted to colder water. Hotter water has less force, colder more force. Wamer surface water is more buoyant. Water pushes air out making it denser.	10
	Surface tension plays a role in ships floating.	1
	The salt water of the ocean is needed to float huge ships.	5
Air	Constant flow of air in the ship distributes the density.	2
	Air at the bottom of the ship helps it to float – air is "trapped" or in a "tank."	19
Ships	Heat from the engine helps the ship stay floating above the cooler water.	6
	Heat from the ship heats the water which helps it float.	4
	Ships have a "buoyant material" at the bottom that has the same density as water.	2
	Ships balance their weight above and below the water line – same amount above and below and they float.	1
	The front edge of the ship plays a role in floating "it leans forward which helps it not to sink because it is puts more pressure on the front."	3
	As the ship moves it pushes up out of the water because it is reaching more space on the water.	1

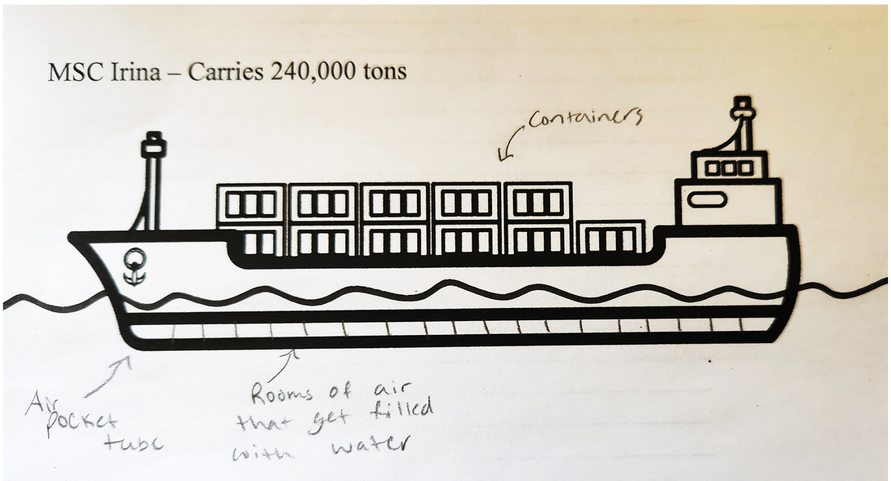

Figure 1. Student pre-investigation model using provided template.

However, the template did not lead students to this misconception. Students in other quarters created their own air chambers (Figure 2). This misconception stood out because these students did not see the air as filling the ship but rather being located at the bottom of the ship like a flotation device. In addition to text in Figure 1 and Figure 2, student descriptions included statements like, "pocket of air," "hollow materials that are buoyant," and "flotation device."

In the second most common misconception, ten students believed that varying temperature layers in the ocean and their influence on cargo ships floating. Some students felt that it was the cold water in the lower layers that were more important in pushing the boat up. Figure 3 is a cropped view of a student model showing a detailed explanation of this misconception. Other students emphasizing the role of cold water stated things like, "denser objects [like ships] are attracted to colder water," and "although the boat is heavy, the water is heavier – cold ocean water = more dense." A few students thought it was the warm water that made the difference stating that, "warmer surface water is more buoyant" and "the hot water rises to the top."

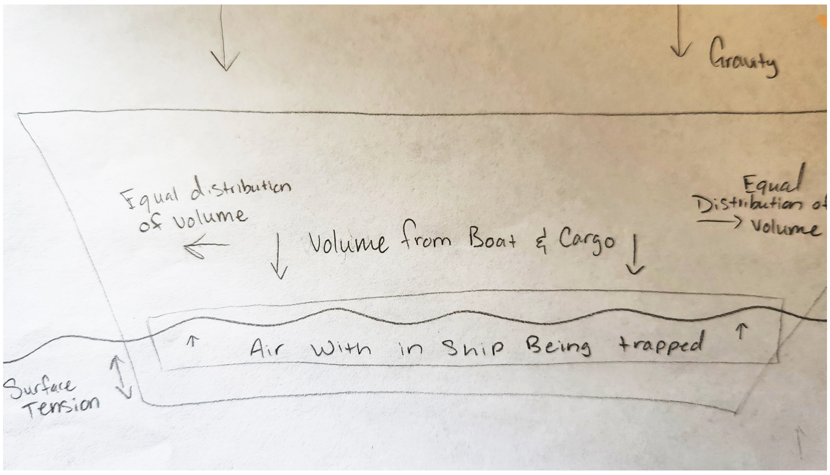

Figure 2. Student pre-investigation model without starting template.

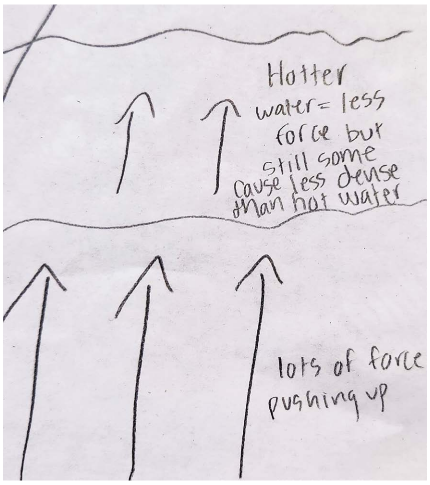

Figure 3. Cropped pre-investigation student model.

Very few misconceptions remained in student post-investigation models. The change in the presence of misconceptions was dramatic (**Figure 4**). Only one student still demonstrated a misconception about the role of water in ships floating. Three students still held onto a misconception about the role of air; however, no one maintained misconceptions about ships in their models. **Figure 5** shows a post-investigation model that is representative of one of the higher scoring models.

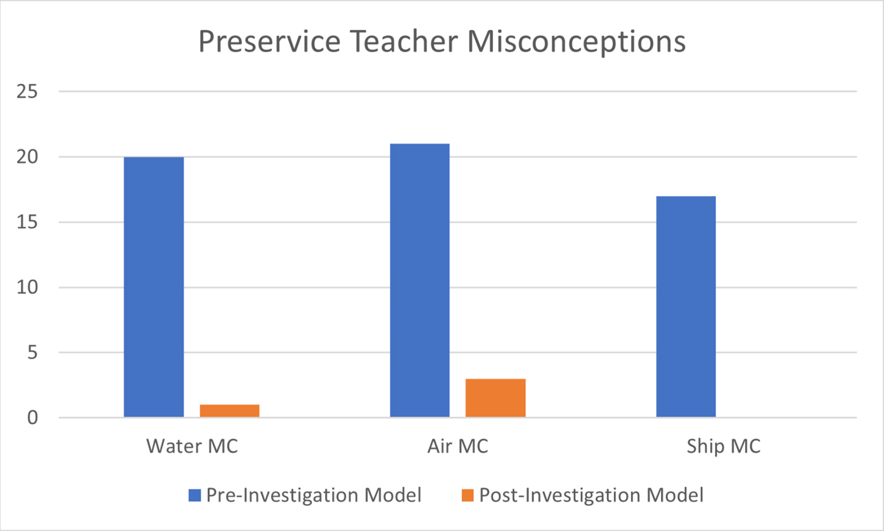

Figure 4. Pre and post-investigation of misconception counts based on models.

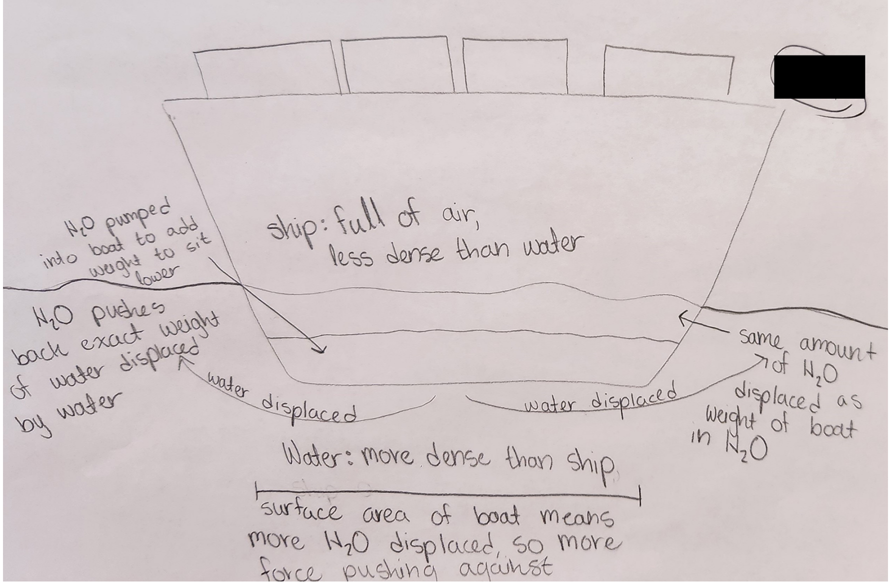

Figure 5. Higher scoring post-investigation model.

5. Discussion

In this study we asked two questions. 1) How effective and consistent is MBI in helping preservice teachers deepen their CK of buoyancy? And 2) What misconceptions do preservice teachers have about buoyancy before and after the MBI lesson sequence? The results from the research indicate that the MBI lesson sequence was very effective in strengthening preservice teachers CK. Misconceptions were found throughout preservice teachers' pre-investigation models but were greatly reduced in the post models.

The MBI lesson sequence on buoyancy and the phenomenon of floating cargo ships proved both effective and consistent. Student growth in CK from pre to post models was statistically significant for each of the four quarters of the study. The results also indicate practical significance; effect sizes for these quarters ranged from d = 2.38 to d = 3.47 which represent very large effect sizes—far above the threshold (Cohen, 1994). These findings in our research match with other studies demonstrating success in building preservice teacher CK in a science methods courses (Correia & Baptista, 2022; Santau et al., 2014). Seeing consistent results with the MBI sequence was encouraging. MBI (at least MBI similar to AST) is quite flexible from class to class as adjustments and changes are made according to student models and hypotheses (Windschitl et al., 2008; 2018). Remaining this flexible and ready to change investigation plans or test a different aspect of phenomenon based on current student ideas is somewhat intimidating. We wondered if we would be able to successfully accomplish this without the loss of growth in CK. Statistically significant t-tests for each quarter gives evidence of consistency. These are further supported by the analysis of variance results as well as the linear regression model. The one-way ANOVA revealed that there was no statistically significant difference in post scores or growth according to quarter. Beyond this, results from the regression demonstrated that the quarter variable was not a statistically significant predictor of post-investigation score. Preservice teachers' CK grew, and their learning was not dependent on the quarter they took the class.

At the beginning of the investigation, many preservice teachers demonstrated misconceptions about how or why cargo ships remain afloat. Nearly all of these were absent from student models at the end of the lesson sequence. This result was particularly encouraging considering the fact that such deep learning is not always documented in students completing college level science courses (Khourey-Bowers & Fenk, 2009) or teacher preparation programs (Lederman & Chang, 1997).

5.1. Limitations

It is important to discuss limitations with this study. While the findings contribute to our understanding as teacher educators and support the use of MBI in a science methods classroom to build preservice teacher CK, caution is needed. First, participants in this study all attended a single institution in the Pacific Northwest, generalizations should be considered carefully. Next, our study does not compare the MBI framework with any other instructional design. The results clearly indicate that preservice teachers grew in CK through the lessons; however, is this growth more or less than they might have grown with a different instructional framework? Second, teaching for conceptual change is very difficult as students hold onto current conceptual frameworks strongly (Treagust & Duit, 2008) and can even successfully demonstrate growth in understanding while continuing to hold tightly to misconceptions (Schneps, 1997). There is no longitudinal aspect to the study to determine how newly founded CK of buoyancy persists or if misconceptions return. Third, PCK was not under investigation in the study. Therefore, nothing can be said about the relationship between CK growth and PCK or if the MBI instructional framework helped to grow preservice teacher PCK.

5.2. Implications

While science methods instructors continue to emphasize PCK, this study indicates that attention can and maybe should be given to developing science CK as well. The purpose of a methods course is to prepare preservice teachers to teach a particular content; therefore, a strong focus on PCK is completely appropriate. At the same time, research has demonstrated that elementary preservice teachers' CK of science is often not strong (Santau et al., 2014; Sorge et al., 2019) and that CK is a limiting factor in the development of PCK (Baumert et al., 2010). By creating an authentic science inquiry experience for preservice teachers using a MBI approach, we were able to demonstrate growth in preservice teachers' science CK while modeling an instructional approach. We want to teach them to go use MBI in their own classrooms anyways. This creative solution allows us to impart both CK and PCK at the same time.

A second issue this study highlights is the perpetuation of misconceptions. Research has demonstrated that one of the challenges of correcting scientific misconceptions is that teachers who themselves believe particular misconceptions may unwittingly reinforce these ideas in their students (Treagust & Duit, 2008). Considering the large number of misconceptions about buoyancy brought to light with our investigation and the dramatic change suggested by the post-investigation models, the time spent developing preservice teacher CK about buoyancy seems justified.

5.3. Conclusion

The purpose of this study was to determine how effective an MBI lesson sequence on buoyancy proved in advancing preservice elementary teachers' CK. The results indicated that the MBI curriculum was effective in each of the four quarters investigated and that no quarter produced different results—even though MBI curriculums are modified by student interaction. Preservice teachers began the investigations holding onto many misconceptions about buoyancy. Post-investigation models demonstrated a stark change in understanding. Nearly all misconceptions disappeared from student work. The results are encouraging; however, more research is needed to further establish a complete understanding of this phenomenon.

The current study did not compare multiple ways to teach buoyancy. Success was demonstrated with the MBI investigation; however, further research is needed to see if similar results occur with another instructional model. For example, in our own methods course, we spend the bulk of the quarter working with the 5E instructional model (Bybee et al., 2006). We use this primarily as we find it the easiest way to prepare preservice teachers, who themselves have little experience with authentic inquiry, to go teach quality science lessons to their own students. Comparing these two instructional methods would be beneficial. Second, misconceptions in science have proven very difficult to remove (Leuchter et al., 2020). While our post-investigation models indicated that many misconceptions had been replaced with a more scientific set of explanations, a longitudinal study would likely demonstrate the actual assimilation of scientific ideas and level of transformation in mental models for these preservice teachers. Finally, this study focused on the development of preservice teacher CK, yet the development of PCK is arguably a more important goal for a science methods course. Extending this current research to explore the development of teacher PCK through this MBI buoyancy investigation is needed before feeling fully confident in the value it brings to our methods course.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix A

Key Concepts of Buoyancy	Full Understanding (3)	Developing Understanding (2)	Limited Understanding (1)	Missing (0)
Balanced Forces	If an object is floating it means that the force of gravity pulling down and the buoyant force, the force of displaced water pushing up, are equal.	A floating object has balanced forces with gravity pulling down and water pushing up.	Balanced forces mean the object will float.	NA
Density of object and fluid	If an object is less dense that the fluid it means that it will be able to displace more water weight than its own weight and will float.	An object will be buoyant if its density is less than the density of the fluid, and it will sink if its density is greater.	Lighter objects float. Or Less dense objects float.	NA
Density and Displacement	There is a direct relationship between the density of an object and the water it displaces when floating. Increasing density displaces more water and decreasing it displaces less. If its density perfectly matched that of the fluid, it could be placed anywhere in the fluid column.	Objects with greater density float lower in the water.	Lighter things float on top of the water.	NA
Weight of Water Displaced	The upward buoyant force on an object in a fluid is equal to the weight of the water the object is displacing. Therefore, an object will float if the weight of the water it displaces is equal to or greater than the weight of the object.	The more water an object displaces the harder water will push up on the object.	Water pushes back harder when an object is bigger and takes up more space.	NA
Cargo Ship & Pebble Phenomenon	The Cargo ship floats because its overall density is less than water. In fact, it is far, far less. They actually add ballast water to cause it to float lower in the water for stability. This is possible even though it is made from iron because it is so very large. Spreading out all that mass over a massive volume means that as the ship sinks into the water it is displacing an incredible amount of water. The amount of water weight it displaces is equal to the weight of the ship and floats. Even though the pebble is small, it is very compact for its mass. This means it is denser and does not displace enough water to balance the forces.	Even heavy things like the ship can float if they are hollow or have enough air in them to lower their density. The pebble wasn't hollow. Or Even heavy things like the ship can float if they have enough volume to spread out so that their weight across the water. This means they displace more water and that water pushes back with enough force. The pebble isn't spread enough.	The ship floats because it spreads out its weight. Or The ship floats because it is less dense than water. And/or The pebble was too small for its weight/more dense than water.	