Development of Phenomenon-Based Science Courses for Elementary Education Majors

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Abstract

This article describes the development and pilot implementation of a two-semester phenomenon-based science course sequence for elementary education majors. The courses were designed to address challenges related to elementary teachers' science content knowledge and to provide opportunities for science learning that intertwine core ideas, practices, and crosscutting concepts. Drawing on the principles of Ambitious Science Teaching, the courses were made up of units focused on an anchoring phenomenon. Student perceptions of the courses gathered through interviews indicated that the courses had a positive impact on how they viewed the process of learning science. Students highlighted the course's focus on the process of learning, the depth of investigation, and the collaborative nature of the learning experience. The article concludes with recommendations for science teacher educators interested in implementing similar courses or course units.

For many years, researchers have documented challenges related to science content knowledge for elementary science teachers (Abell, 2007; Brobst et al., 2017; Van Driel et al., 2014). Furthermore, the experiences that elementary education majors have had learning science may often present science as a collection of facts and vocabulary (Banilower et al., 2013) rather than offering opportunities to engage in three-dimensional learning that intertwines core ideas, practices, and crosscutting concepts (National Research Council, 2012). As a result of these factors, elementary teachers may face challenges in providing quality science instruction for their students. This article describes the development of a two-semester sequence of phenomenon-based science courses for elementary education majors and shares the perspectives of students who were enrolled in the courses.

Background

Typically, as part of their undergraduate coursework, elementary education majors take at least one science content course as well as a science methods course focused on pedagogy. At my institution, like at many others, science content courses are selected from a list of approved courses designed for non-STEM majors, which tend to focus on a narrow content area. At some institutions, the content courses offered to elementary education majors are specifically designed for them, but even in these cases, they tend to have narrow content foci as well (e.g., Awad & Barak, 2018; Bergman & Morphew, 2015; Cervato &

Kerton, 2017; Riegle-Crumb et al., 2015). In both cases, content courses may be taught using more traditional approaches, such as lectures paired with labs that do not model the type of pedagogy elementary teachers should implement in their classrooms.

During their teacher education coursework, elementary education majors typically take at least one semester of a science methods course. The focus of these methods courses is on pedagogical practices for teaching science to elementary students. In methods courses, science activities are used to model particular teaching practices instead of explicitly teaching science content ideas. The resulting situation is that many elementary education majors graduate from their teacher preparation programs with limited experience learning science in ways that model the types of pedagogical approaches shown to be effective for elementary students.

In an attempt to address these issues, I developed a two-semester sequence of science content courses that were based on the principles of Ambitious Science Teaching (AST) (Windschitl et al., 2018). AST was chosen because of its potential to support the kind of three-dimensional science learning envisioned by *Framework for K-12 Science Education* (National Research Council, 2012) and its focus on rigor and equity. In this context, rigor is defined as encouraging students to go beyond their current levels of understanding of science, while equity ensures that all students have the opportunity to participate in science and are treated as valuable members of the science learning community (Windschitl & Barton, 2016). The AST model of teaching asks teachers to engage in a set of four core practices: planning for engagement with important science ideas, eliciting students' ideas, supporting ongoing changes in thinking, and pressing for evidence-based explanations (Windschitl et al., 2018). The AST practices require teachers to understand the important science ideas (content) and be willing to engage in a certain level of uncertainty with their students.

A key component of the AST instructional framework is using scientific phenomena (sometimes called anchoring events) as a frame for instructional units (Windschitl et al., 2018). By connecting scientific phenomena to science teaching, students may gain understandings not only of science content but also about the nature of science as a discipline that seeks to explain natural phenomena. Traditionally, science teaching has focused on general science knowledge, which may seem disconnected from everyday experiences and real-world contexts (Achieve, Inc. et al., 2016; Banilower et al., 2013). In a phenomenon-based approach to science teaching, "the focus of learning *shifts from* ***learning about*** *a topic to* ***figuring out*** *why or how something happens*" (Achieve, Inc. et al., 2016, p. 1). This important shift allows students to build scientific knowledge and use it to explain phenomena that support deeper understanding (National Research Council, 2012).

For prospective elementary teachers likely to have had traditional science instruction, a phenomenon-based science course will not only support a deeper understanding of science content (Grinath & Southerland, 2019) but also provide a model for their own future science teaching. As teachers, they will be expected to teach science in a way that supports students engaging in the three dimensions of the NGSS. Phenomenon-based science is ideally suited to achieve this goal. To build an explanation of a phenomenon, students are required to apply disciplinary core ideas and crosscutting concepts through their use of the practices of science and engineering (Achieve, Inc. et al., 2016). This might be a challenge for some prospective elementary teachers because this type of teaching can be a daunting concept, especially if you feel uncertain about your own understanding of the content ideas you are teaching. Haverly et al. (2018) found that uncertain content knowledge had a negative impact on novice elementary teachers' ability to provide opportunities for equitable sense-making, one of the key aspects of the AST model.

This article first describes the context and design of a two-semester course sequence of phenomenon-based science content courses for elementary education majors. Then, I offer a more detailed description of one of the course units as an illustrative example. Students' perspectives on the courses are shared, and finally, I offer some recommendations for science teacher educators.

Context and Design of the Courses

The aims of the two-semester course sequence (Elementary Education Science I and Elementary Education Science II) were to provide elementary education majors with a broader introduction to science content while at the same time offering an opportunity to learn science in a way that was likely different from what they had experienced in earlier science courses. This section will provide an overview of the course design process and the context of the course's pilot implementations. In the following section, a more detailed description of one of the units will be provided. All the course materials will be available for download at https://sites.google.com/nau.edu/ecast/home.

To design the phenomenon-based courses, I drew on the principles of Ambitious Science Teaching (Windschitl et al., 2018) and used the disciplinary core ideas (DCIs) from the NGSS standards for grades K-8 (NGSS Lead States, 2013). While it was impossible to include all the DCIs, I made choices to focus on those that were most common in K-8 standards. The Elementary Education Science I course focused primarily on life science topics, and the Elementary Education Science II course focused on physical science and earth and space science topics. I then chose central phenomena for each unit (eight total, four in each semester) that would support the greatest number of DCIs. To choose these phenomena, I utilized characteristics of good anchoring phenomena (Penuel & Bell, 2016) and consulted with other phenomenon-based science curricula (Gray & Campbell, 2023; *OpenSciEd*, n.d.; University of Colorado Boulder, n.d.). The list of phenomena that were used and their relevant DCIs can be found in Table 1.

Table 1

List of phenomena and relevant DCIs

Table 1

Course Units and Content Ideas

Course	Phenomenon	Disciplinary Core Ideas
Elementary Education Science I	Duchenne Muscular Dystrophy	From Molecules to Organisms: Structure and Processes Heredity: Inheritance and Variation of Traits
	Lampsilis Mussels	Biological Evolution: Unity and Diversity
	General Sherman Tree	From Molecules to Organisms: Structure and Processes Ecosystems: Interactions, Energy and Dynamics
	Orangutans and Palm Oil	Ecosystems: Interactions, Energy and Dynamics Earth and Human Activity
Elementary Education Science II	Polar Ice Melt	Energy Earth's Systems Earth and Human Activity
	Thermal Cups	Matter and Its Interactions Energy
	Manhattanhenge	Earth's Place in the Universe
	Mountain Formation	Earth's Systems

After selecting the phenomenon for each unit, I followed the process outlined in *Ambitious Science Teaching* (Windschitl et al., 2018) to write a gapless explanation (the complete causal storyline that explains how a particular scientific phenomenon occurs) and, from that, outline the investigations and activities that would be part of each unit. Each unit was structured in the same way:

- Introduction of the Anchoring Phenomenon
- Sharing of Initial Ideas
- Creation of Initial Explanatory Model
- Activities and Investigations – Completion of Summary Table Entry After Each
- Creation of Key Ideas for Final Models List
- Creation of Final Explanatory Model
- Writing Final Explanation
- Completion of Application Task

Except for the final written explanation and application task, everything was completed in small groups or as a whole class discussion. This choice was intentional to support student sense-making through a sociocultural approach (Vygotsky, 1978) but also to provide some individual accountability for students.

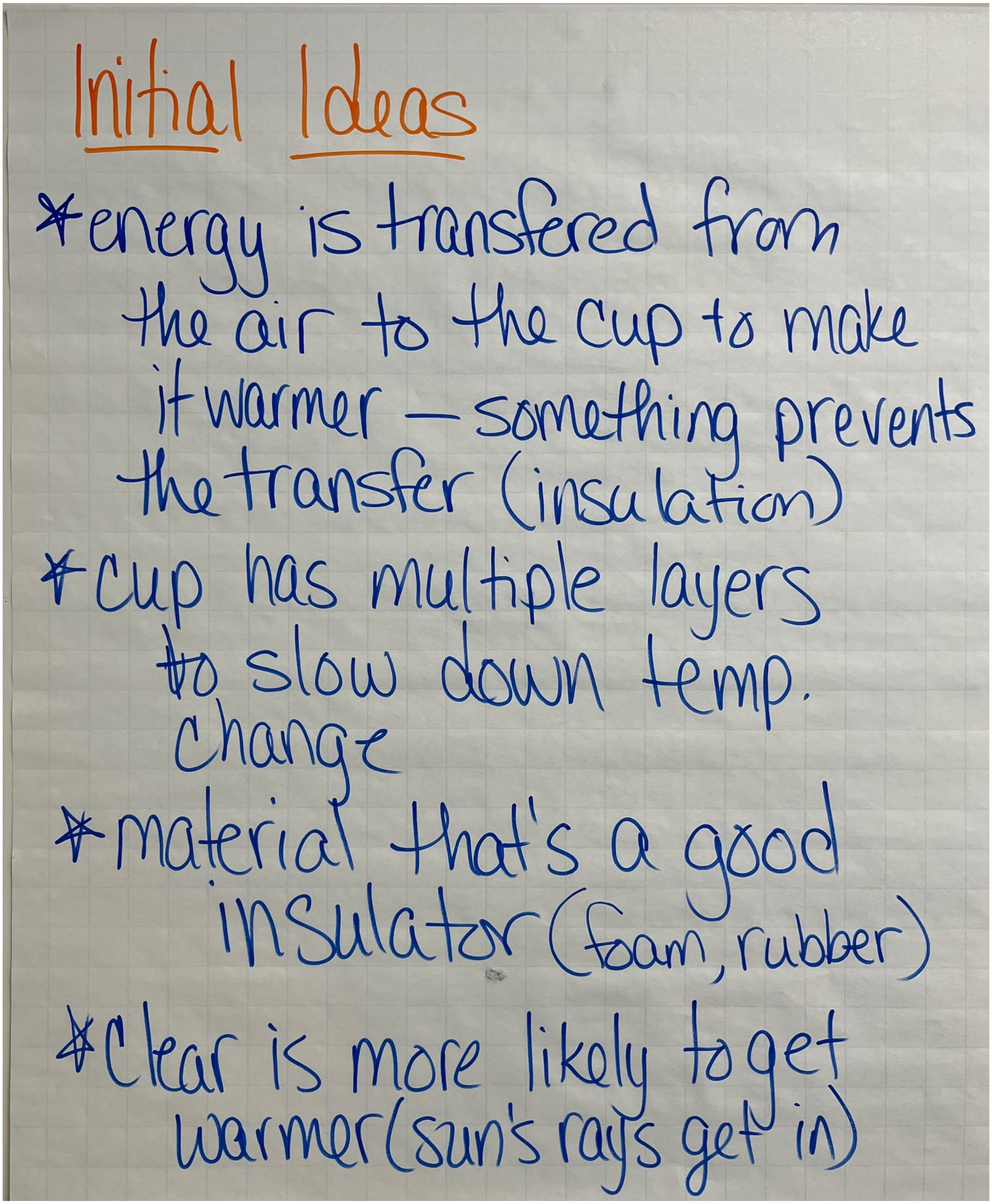
To guide students' work in the unit, I created an electronic notebook for each student in Google Slides that contained all required readings, directions for investigations, places to record observations and conclusions, and a summary table page. All work except for the final explanation and application task was completed in this notebook. Notebooks were periodically checked for completeness, and feedback on students' work was provided. The advantages of the electronic notebook included it was provided at no cost to students, all materials were in one place, links to additional resources could be provided, it was accessible by students as well as faculty at any time, and students could share and collaborate in their notebooks as desired. There were also a few disadvantages, including time to set up and share the notebooks at the beginning of the semester. The notebooks worked best on a laptop/tablet, and occasionally, students would forget their device or charging cable and use their phones instead, which was not ideal. On rare occasions, a student's device had difficulties connecting to the Internet, which is required for using Google Docs. This final issue could be addressed by having students set up their Google Docs to be able to be edited when offline and then sync when connected to the Internet. This solution proved very workable for one student who had consistent issues connecting their device to the Wi-Fi network in the classroom.

The courses were piloted in the 2022-2023 and 2023-2024 academic years. Given that they were pilot courses which, at the moment, were electives and did not fulfill any major or university requirements, the numbers of students enrolled varied considerably between the semesters. Across all four semesters that the courses were offered, 51 students were enrolled in the courses. While the ultimate goal for the courses is that they will be taken as a two-semester sequence by first- or second-year elementary education majors, these requirements were relaxed for the pilot implementations. Therefore, while most students fit the targeted year and major, there were a few who did not. Additionally, not all students were able to enroll in both semesters, and some enrolled in the spring course first and in the fall course the following year. As the units in the courses are relatively independent of one another, this did not present any issues with curricular continuity.

Sample Unit: Thermal Cups

The Thermal Cups Unit is centered around the question, "How can cups keep things from heating up or cooling down?" This unit is especially relevant for students since many of them have water bottles and cups that are advertised as keeping drinks warm or cold for longer than "normal" bottles and cups. This unit was adapted from the *Thermal Energy* unit from the OpenSciEd (*OpenSciEd*, n.d.) curriculum. Activities were adapted to fit the context and format of an introductory-level undergraduate science course. The unit phenomenon was based on a short investigation to test the claim that a "fancy" cup will keep a drink colder longer than a "normal" cup. Students were provided with materials (clear plastic double-walled cup with lid and straw (fancy cup), clear plastic single-walled cup with lid and straw (normal cup), thermometers, cold water) and asked to collect data to test the claim. Following data collection that led to the conclusion that the fancy cup did indeed keep the water colder longer, the class discussed and recorded initial ideas about why that happened (see Figure 1).

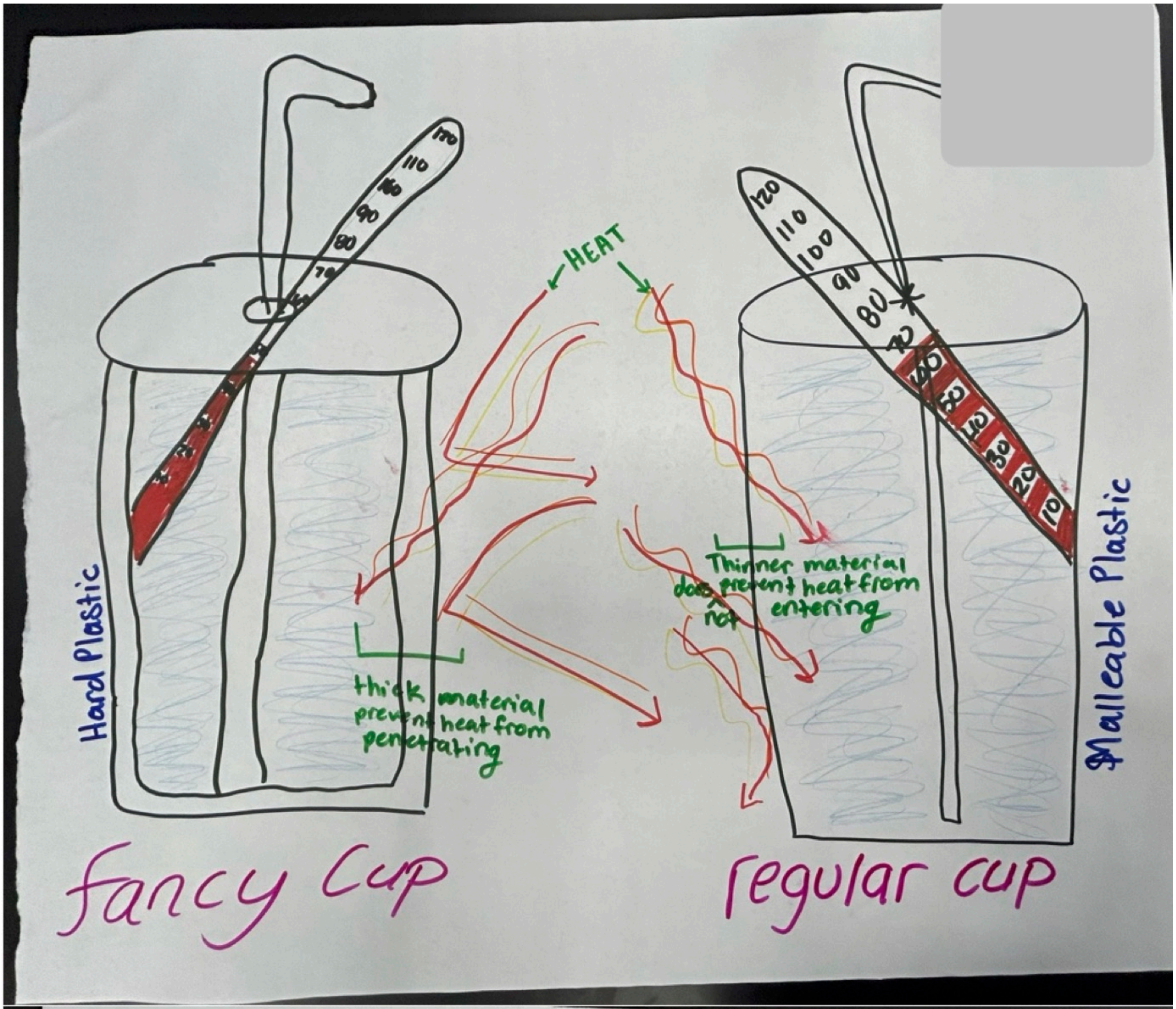
Figure 1
Students' initial ideas

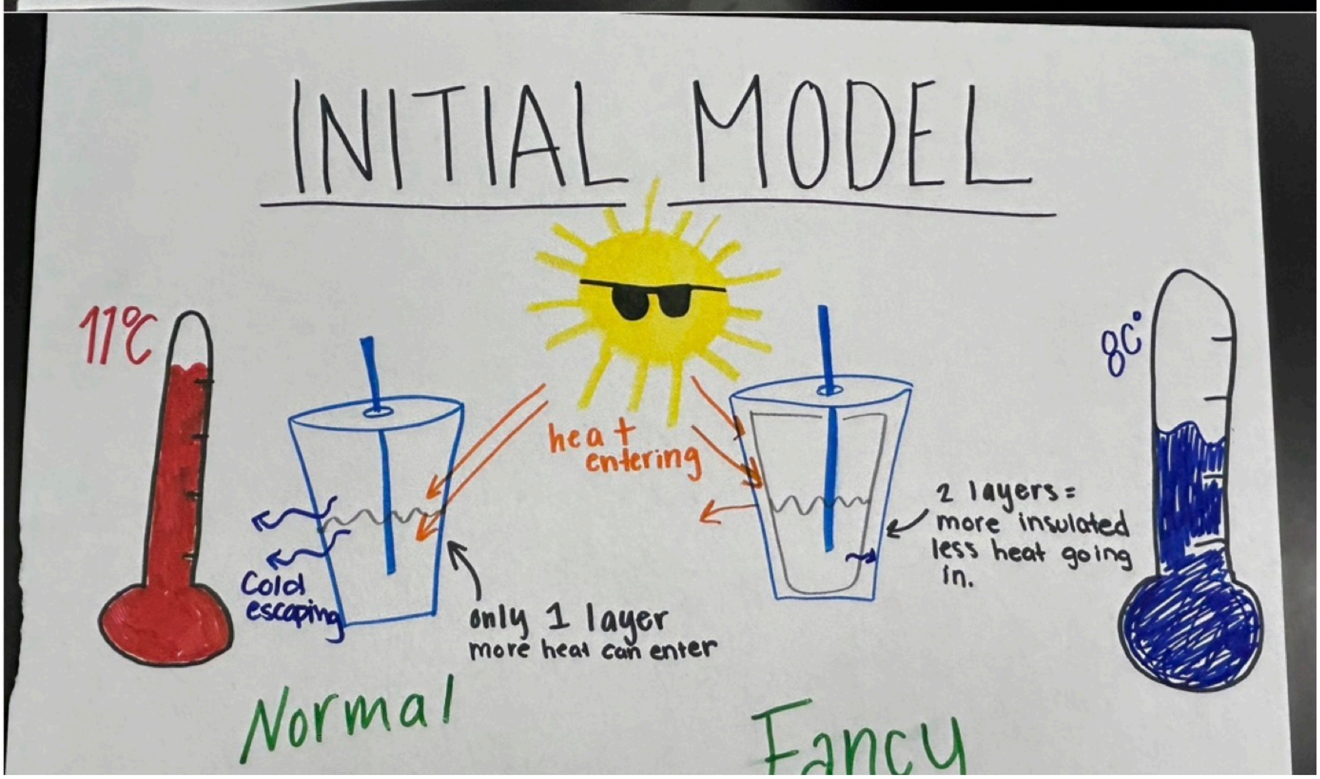


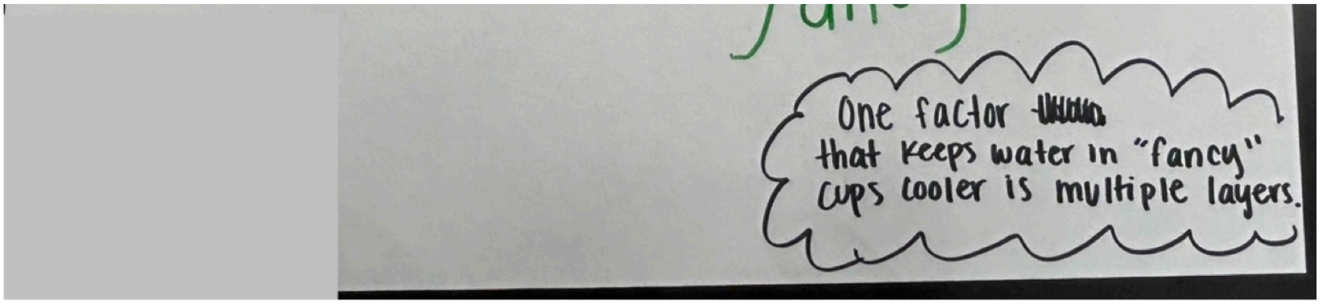
Finally, each group worked together to create an initial explanatory model for how cups can keep things from heating up or cooling down (see Figure 2 for examples).

Figure 2

Initial explanatory models


HEAT
Hard Plastic
thick material
prevent heat from
penetrating
Thinner material
does not prevent heat from
entering
Malleable Plastic
fancy cup
regular cup


INITIAL MODEL
11°C
8C°
heat
entering
Cold
escaping
only 1 layer
more heat can enter
2 layers =
more insulated
less heat going
in.
Normal
Fancy



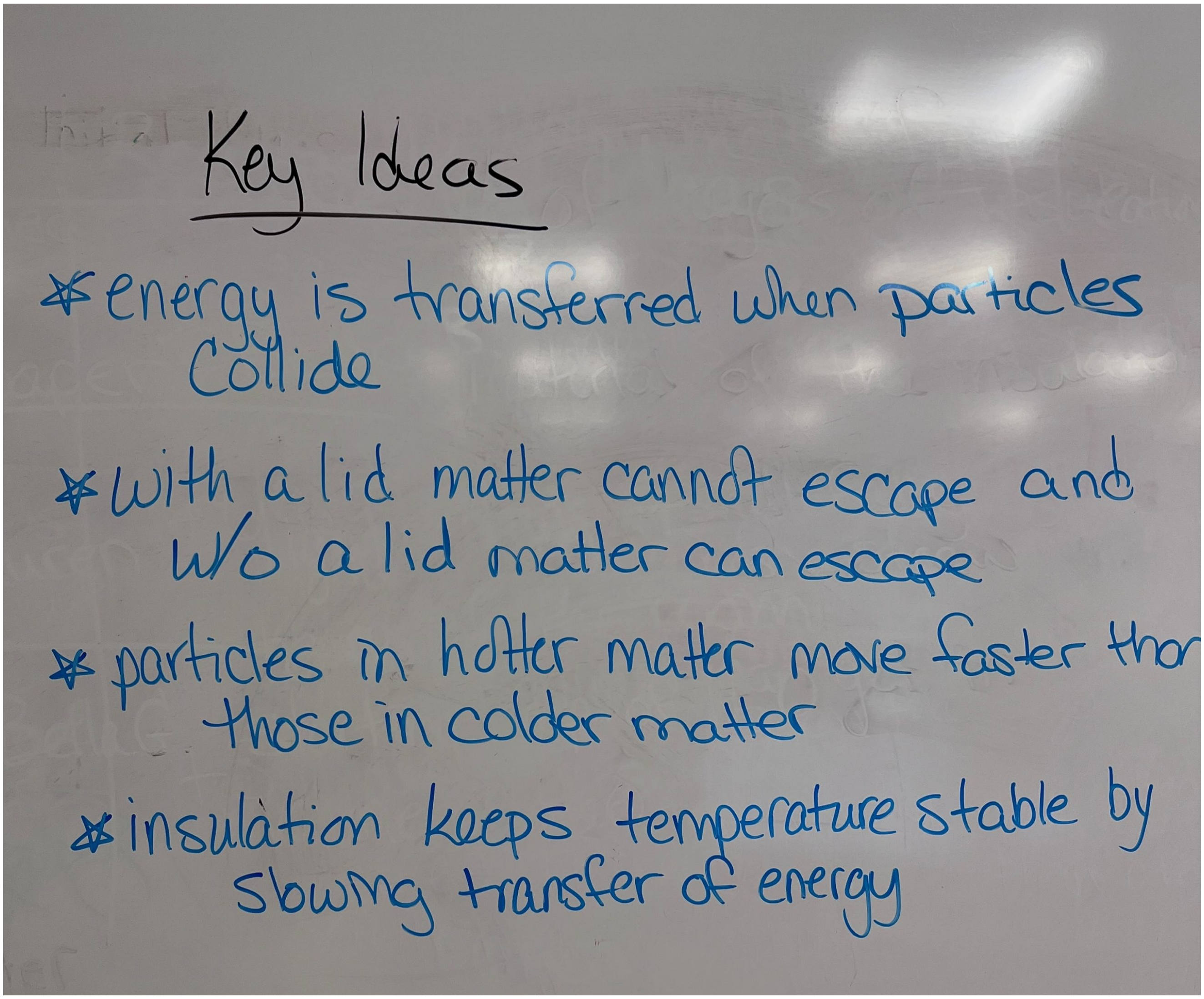
Over the course of the four-week unit students engaged in explorations in order to be able to answer the unit's driving questions. These activities included:

- Brainstorming which cup features might make the biggest impact on temperature retention and designing an investigation to test the impact of different features
- Investigating cup features (material (metal, paper, plastic); lid/no lid; straw/no straw; and single/double walled) with cold and hot water
- Investigating what happens to the temperature and mass of hot water over time in a cup with a lid versus a cup without a lid
- Developing a model to explain the loss of mass from the hot water in the cup without a lid.
- Exploring particle representations of matter
- Using provided data to investigate what happens when water in an airtight container changes temperature
- Investigating the movement of heat or cold in a closed system
- Exploring what might be causing heat/cold to move by watching a video of candy dissolving and exploring the movement of food coloring in water of different temperatures
- Reading about James Joule's experiment moving a weight through water and measuring changes in temperature and then using his findings to help explain what was observed with the candy and food coloring
- Using a particle motion simulator to explore particle interactions in gases and solids at different temperatures

Following each activity, the class worked together to complete an entry in the unit summary table. Each entry summarized what was learned or figured out in the activity and how it might help to explain the unit phenomenon. At the conclusion of the unit, the class worked together to create a list of key ideas that should be included in the final model (see Figure 3).

Figure 3

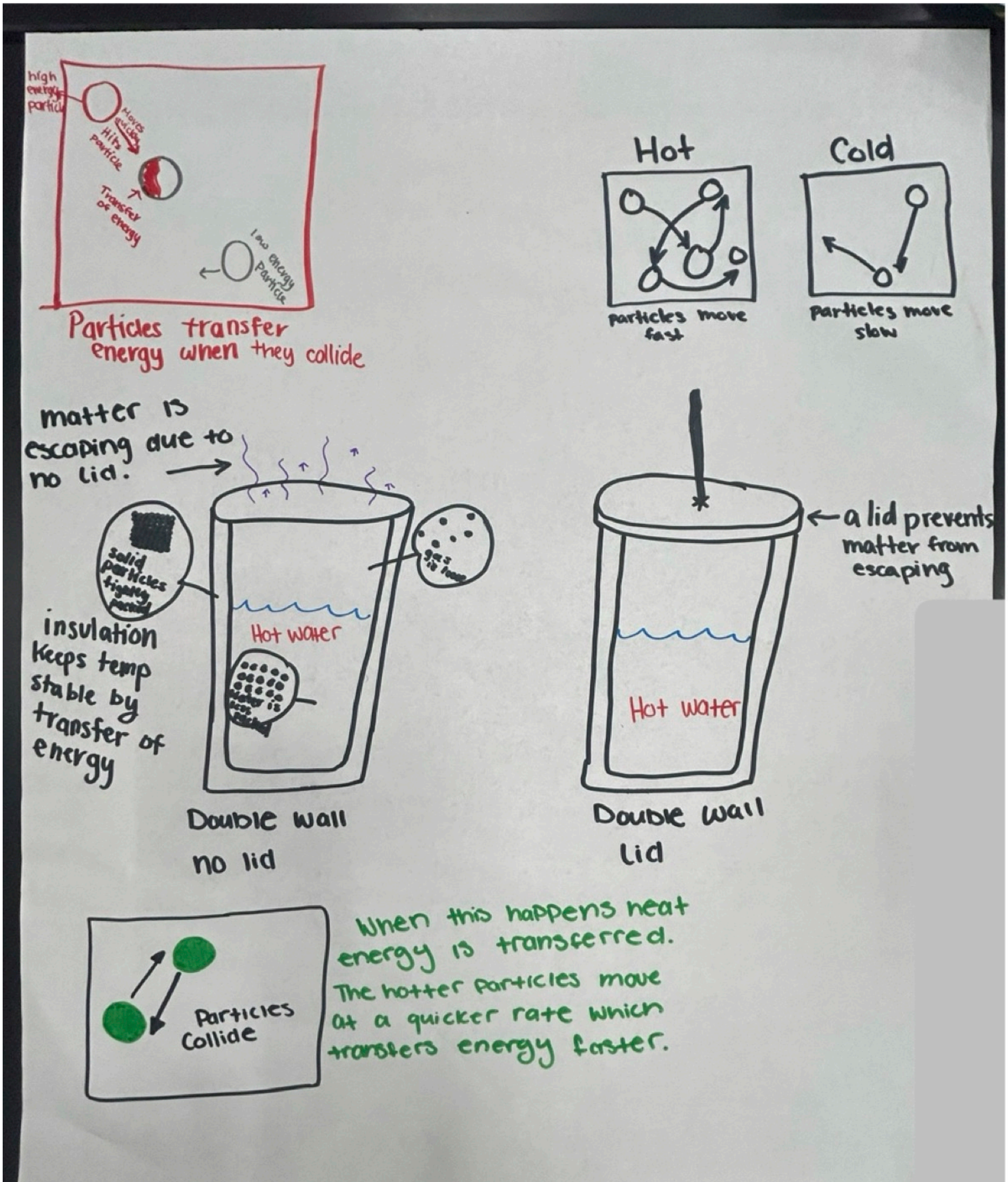
Key ideas for final model

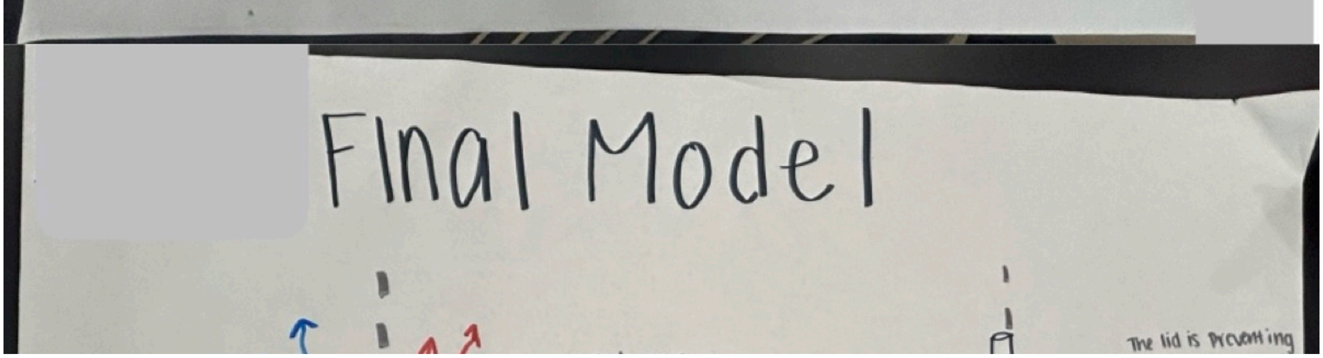


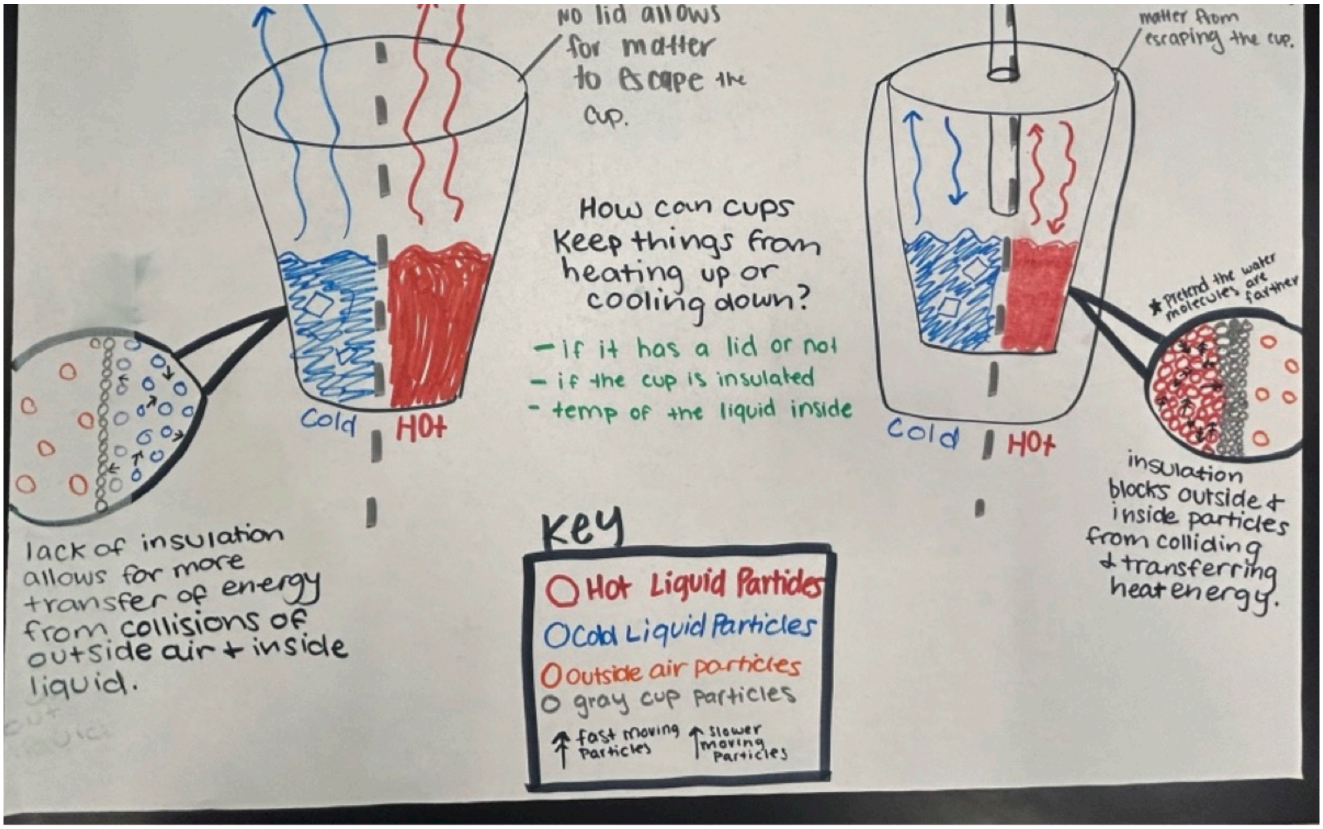
Then, each group created a final explanatory model for the unit phenomenon (see Figure 4 for examples).

Figure 4

Final explanatory models


high energy particle
moves quickly
Hits particle
Transfer of energy
low energy particle
Particles transfer energy when they collide
Hot
Cold
particles move fast
particles move slow
matter is escaping due to no lid.
solid particles tightly packed
gas is loose
insulation keeps temp stable by transfer of energy
Hot water
Double wall
no lid
a lid prevents matter from escaping
Hot water
Double wall
lid
Particles Collide
When this happens heat energy is transferred.
The hotter particles move at a quicker rate which transfers energy faster.


Final Model
The lid is preventing



In this unit, following the creation of final models and written explanations, students worked in groups to apply their knowledge to the cold cup challenge. In this challenge, students worked in their groups to use what they had learned about thermal cups to design a cup that would keep water cold the longest in normal room lighting as well as when placed in direct light from a desk lamp. Groups were provided with access to a variety of materials (e.g., aluminum foil, plastic wrap, foam, tape, glue) and a price list for the materials. There was an upper limit on the amount that could be spent on materials and groups competed for who could make the cheapest cup that worked the best. For each feature of the cup that they designed, students were asked to explain why (using what they had learned in the unit) that feature was included.

At the conclusion of each unit, students were asked to write a final explanation and complete an application task. Each of these things was completed individually and took the place of more traditional course assessments like quizzes or exams. Prior to completing the application task, students had a chance to read the task, and then there was a whole class discussion about what ideas from the unit might be helpful in relation to the application task. For the thermal cups unit, the application task asked students to explain how heat energy moved in a situation where an ice pack was applied to an injury (see Supplemental Materials). This application task was adapted from the OpenSciEd unit (*OpenSciEd*, n.d.).

All students enrolled in the courses were invited to also be part of a research project that focused on the effectiveness of this model of teaching for undergraduate science courses, as well as in what ways, if any, the course impacted their views of science teaching.

Participation in the research study was not a requirement of enrollment, but most (75%) students who enrolled in the course also chose to participate in the study. I was both the instructor for the course and the principal investigator for the study. Therefore, to mitigate any chance that students would feel undue pressure to participate in the study recruitment, consent for the study was obtained from another faculty member. I was not aware of which students had consented to be part of the study until after course grades had been submitted.

Student Perceptions of the Course

As part of the research project, students participated in interviews at the beginning and end of the course. This section will share findings from a question asked during the end-of-course interview: “How would you describe this science class to someone who was thinking about taking it in the future?” Thirty-eight students consented to be part of the study, but only 27 (53% of all enrolled students) completed an end-of-course interview. The analysis of student responses began with a process of in vivo open coding of the transcripts of interviews (Saldana, 2021). These codes were then categorized into themes, which are presented here.

The theme that arose most frequently (in 56% of student responses) was the idea that the course focused on the process of learning. As Olivia (all student names are pseudonyms) put it when describing what she tells people about the course, “I also make sure to, like, emphasize that this class is really more about the learning process, and not about getting the right answer on the first try.” She went on to describe how she responds when peers express uncertainty about enrolling in the course.

Sometimes I’ll tell people about the class, and they’re like, “Oh, well, I don’t know. I’m not really, like, a big science person. I’ve never really been good at it.” And I’m like, “That’s the point – like, you just get to, like, focus on the learning process itself. It’s not about, like, being good at science.”

Olivia’s response highlighted one of the primary goals of the course, which was to engage students in a way of learning science that went beyond approaches that focus on learning a collection of facts and instead supported the development of understanding how things work.

Related to the idea that the course focused on the process of learning science, several students also commented on the depth in which class topics were investigated.

I would say it’s a very collaborative and creative class where you’re exploring like, not like, super difficult phenomenons [sic], but, like, delving deep into phenomenons [sic] and breaking them down into pieces, and really like, getting an understanding of each of the pieces, and how they relate back to the bigger picture through like experiments and collaboration. (Savannah)

Connected to the idea of thinking more deeply about things, Faith shared about how the course encouraged this type of deep thinking. They said, “We are given questions that really kinda help us think about it deeper.” Students’ written final explanations for the phenomena generally supported the idea that they had developed deeper understandings of the science that underlay the phenomena. Their work on the application tasks was more variable in terms of how successful students were in applying the ideas from one phenomenon to a different phenomenon.

In her comment shared above, Savannah highlighted the idea of collaboration as a key feature of the course. Responses, including references to collaboration and team/group work, were the second most frequent category. One example of how students described the collaborative aspect of the class came from Sarah:

I would describe it as super, like, groupwork focused, and more like a collaborative science rather than like some classes, that at least I’ve taken in the past, where it’s more like, independent. This one is more like, class-oriented to like, everybody does things together.

Sarah’s comment highlighted the idea of group sense-making, which was a key design principle of the course. This is also something that I highlighted throughout the course with frequent reminders to discuss ideas within the small groups and through intentional design choices that required groups to work together to be successful.

Overall, student responses to the course were positive. Many included descriptions of the class as “fun” or “enjoyable.” Some contrasted it with other classes they had taken, both earlier science courses as well as courses in other subject areas. As Ella concluded, “I didn’t have to, like, think about, ‘Oh, my gosh, I have this class, and it’s so stressful,’ it was more like, ‘Oh, I get to go to class. And I wonder what we get to do today.’” There were no negative comments or suggestions made during the interviews. However, an anecdotal comment made on Rate My Professors indicated that at least for one student in the first semester of the course, there was a misunderstanding about the level of science content that was part of the course. This student indicated that they believed the content would be elementary school level rather than college-level science content. In future semesters, I clarified at the beginning of the course that while the big ideas were based on ideas taught in elementary classrooms, the course examined these ideas from a college-level perspective.

Conclusion

It appears the phenomenon-based science content courses that were part of this project had an impact on how the students perceived the process of learning science. From their descriptions of the course, it is evident that some of the intentional course design principles left an impression on students’ ideas about possibilities for science teaching and learning.

Additional research is currently underway to follow these students in the rest of their teacher education program and early years of teaching to investigate what impact, if any, taking these courses has on their future teaching of science in their own classrooms.

Ideally, elementary education programs would be able to implement a sequence of these types of science courses for all majors. However, there are several constraints that programs might face in doing so. Firstly, most programs do not have room in their requirements to add additional courses. One way to address this is to work to replace general education science course requirements with courses designed specifically for elementary education majors rather than adding additional course requirements to the program. This is the long-term hope for our institution where two lab science courses are required for all students. Secondly, by their nature, these types of courses require smaller caps on enrollment (ideally around 25 students in order to support the integrated approach of investigation and discussions) than the more typical large lecture-lab style courses that are often offered as non-major science courses. Additionally, the way in which these courses should be taught requires preparing instructors to engage in a type of instruction that they may not be familiar with. Addressing these constraints requires an institutional investment and commitment to providing elementary education majors with a different type of science learning experience. However, if large-scale change is not possible, given institutional and programmatic constraints, individual instructors can make smaller-scale changes within their courses. One example of this would be to use one phenomenon-based science unit as a model unit within a methods course to model this type of three-dimensional science teaching in that context.

Author Note

I have no known conflict of interest to disclose. Correspondence concerning this article should be addressed to marti.canipe@nau.edu

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