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Exploring the Depths: Inquiry to Apply and Deepen Students' Understanding of Density

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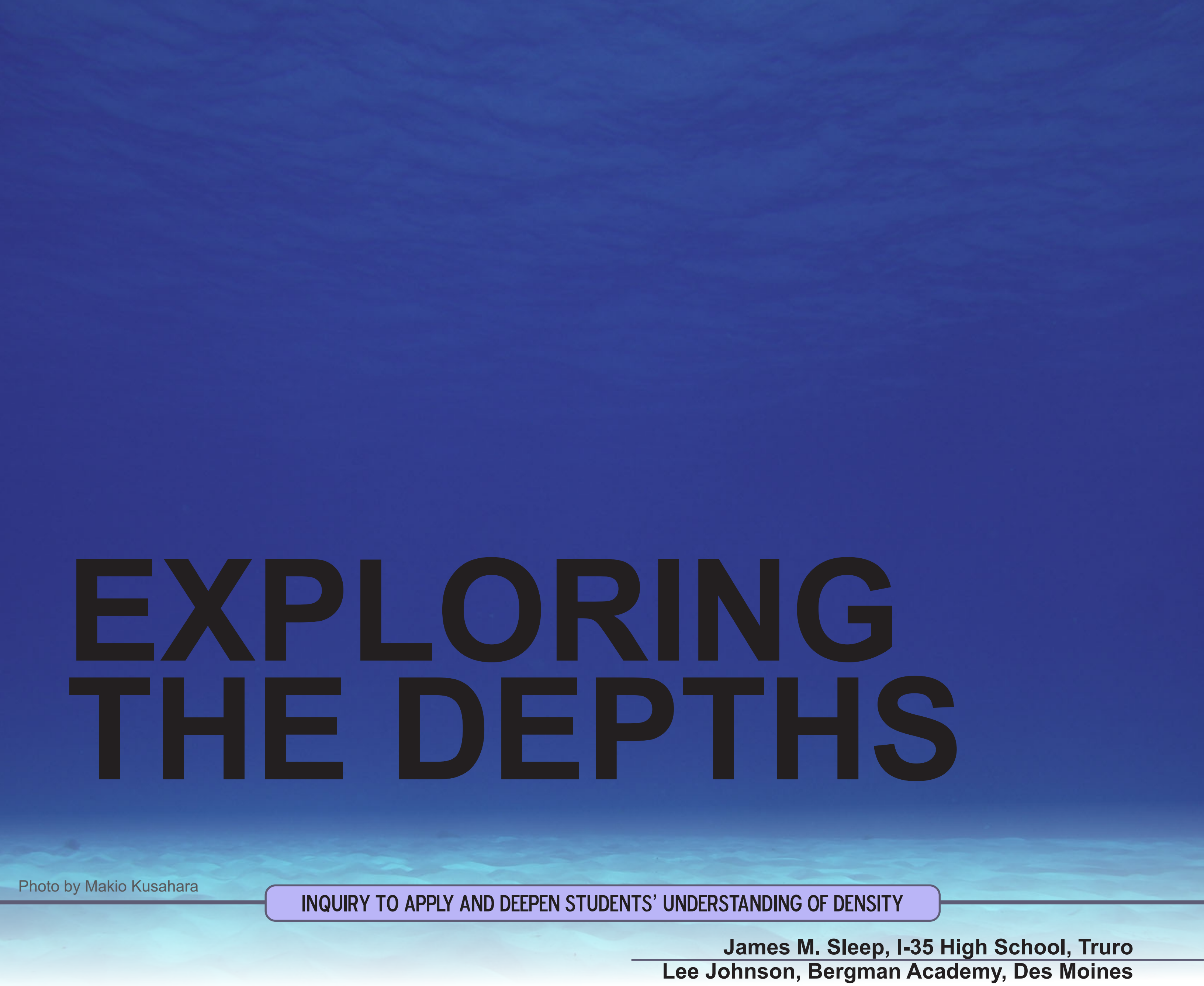

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EXPLORING THE DEPTHS

INQUIRY TO APPLY AND DEEPEN STUDENTS' UNDERSTANDING OF DENSITY

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ABSTRACT: This activity is designed to deepen students' understanding of the concept of density through scientific inquiry. Students devise procedures to determine the relative and absolute (qualitative and quantitative) densities of several solutions of salt water, and establish a class consensus on their results. Students then apply their findings to estimate the density of an unknown solution. The targeted grade-level for this activity is 8^{th} grade physical science. However, because we know students at all grade levels struggle to understand density, this activity could also be useful in high school Earth science and chemistry. *This activity promotes National Science Education Content Standards A, B, and G, and Iowa Teaching Standards 1, 2, 3, and 4.*

Density is a concept that underlies many topics addressed in a typical K-12 science education including severe weather and rock formation in Earth science, the gas laws and separation of mixtures in chemistry, and buoyancy in physics. Because this idea is required in accurately explaining these and other natural phenomena, effectively teaching this concept to students is crucial. However, the abstract nature of this concept makes it difficult for students of all ages to deeply understand.

Perhaps the most widely-held misconception related to density can be referred to as the "weight-density illusion" (Kohn, 1993). Children and adults often inaccurately expect small, heavy objects to float and large, light objects to sink. This may be attributed to the breadth of experiences we all have in the "real world" — large objects tend to be heavier than small objects. This tendency to explain floating and sinking in terms of weight *or* size, rather than integrating the relevant concepts of mass *and* volume, persists into adulthood for many learners despite science teachers' intense effort (Hardy, Jonen, Moller, & Stern, 2006).

In an attempt to alleviate this difficulty with our students, we have modified a widely used activity to be more consistent with education research, reform documents, and state standards. This modified activity models scientific inquiry by investigating the relative and absolute densities of five solutions. Students devise their own procedures, analyze data, and communicate their findings, much like scientists do in their own inquiries. The mental engagement we demand of our students promotes deep understanding of density, and this activity can be a fruitful context to scaffold back to when discussing more complicated concepts (weather, plate tectonics, gas laws, buoyancy, etc.).

This activity is an application activity occurring late in the learning cycle. Before this activity, students have already investigated density in our classes; this activity is meant to help students continue to mentally wrestle with this difficult concept and deepen their understanding before we apply it to other concepts.

Inquiry Activity

Setting Up The Activity

Before starting this activity, prepare five solutions of colored salt water in two-liter bottles. Add 1 cup of table salt to one bottle, ¾ of a cup to the second bottle, ½ a cup to the third bottle, and no salt in the last bottle. Also prepare an "unknown" solution containing ¼ cup of salt. Only the teacher will know how much salt is in the unknown. Add several drops of food coloring unique to each bottle, noting the color of each solution for future reference. We label each bottle "Salt Water Solution – Do Not Drink" to remind students of appropriate lab behavior. Other materials to have ready for students include cups and droppers so students can transfer the four solutions. We also have one test tube per student so all can participate in the investigation on Day 1.

Day 1

To begin this activity, show students the four colored solutions of salt water (excluding the unknown). Many students will be intrigued by these solutions because of their vivid colors. Pose the following scenario to students:

"*I prepared these four solutions of salt water yesterday, each with a different density. What are some ways that we can compare the densities of these solutions?"*

At this point, the teacher or a student writes students' responses on the board. Because students have previously investigated density, we expect the following types of responses:

Density = mass / volume. Measure the mass and volume of a sample of each, and calculate the density of each.

We could mix them all and see what happens.

We know less dense liquids float on more dense liquids, so we could pour one on top of another and see what happens.

See how an object of known density floats on the liquids.

Extensive wait time and inviting nonverbal behaviors (e.g. inquisitive, smiling, looking at all students, etc.) will be necessary in drawing out students' ideas. If students do not suggest the second or third response listed above, encourage students to think deeply to apply their knowledge of density by stating,

- *"How could you do this without a balance or scale?"*

After generating a list of students' ideas, ask students to analyze the pros and cons of each idea.

After this discussion, we encourage students to begin developing specific procedures - reminding them that they will not be allowed to use a balance or scale. We give students a few minutes to talk in pairs. While student pairs discuss, we walk around the room, listen in on students' conversations, and ask questions to keep students moving forward in their discussions. Questions we ask might include:

- *"What problems might you encounter with your procedure?"*
- *"How will you keep track of your results?"*
- *"How much of each solution will you need?"*

CLASSROOM SAFETY

Before allowing students to mix the solutions, their procedures must be approved by the teacher. Also, be sure to address safety concerns. In particular, ask students,

- *"In general, what potential safety issues exist with mixing unknown solutions?"*
- "*How do you know it is safe to mix these unknown solutions?"*

Even though we began the activity by telling students each bottle contains salt water, we ask these questions to be consistent in our effort to always have students *think* about safety issues, both in and out of school. Thus, we also, ask students,

- *"Generally speaking, how should all chemicals we work with be disposed?"*

Explicitly draw students' attention to the idea that they should always place chemical waste in the disposal container provided and never pour chemical waste down the drain. Again, we do this even when working with salt water so that we build a habit of mind and action not to pour chemicals down the drain.

After a few minutes, and after receiving teacher approval, students begin testing their ideas. We ask them to record their observations for each test. Tell students they must give physical, written, and verbal evidence for whatever conclusion they reach regarding the relative densities of the solutions.

Some students may begin by mixing all four solutions. As students finish mixing the solutions, we might ask them,

- *“What did you observe about the solutions when you mixed them?”*

If students do not dismiss this as a viable test, ask,

- *“How useful do you think this procedure will be in determining the relative densities of these solutions?"*
- *"How could you add A to B in a way that would minimize mixing?”*

If these students do not eventually move on to the third idea listed above, ask them,

- *“What other ideas did the class come up with that might be useful to you?”*

Students attempting to layer the colored solutions may find this task to be difficult, especially in preventing unwanted mixing of solutions. The teacher can assist groups who struggle with this task by asking questions such as,

- *“What did you observe when you put A on top of B? If that's the case, what might that mean about their densities?"*
- *"What else might you try? How might the way you're combining the solutions cause unwanted mixing?"*
- *"How might you adjust your method to avoid this problem?”*

If students attempt to immediately combine all four solutions (like they might with vegetable oil, water, and corn syrup), ask questions like,

- *“How could you make this task more simple?"*
- *"How could you be more careful in your layering?”*

Through testing, students should begin to make inferences regarding the relative densities of the four solutions. As students finish testing, ask them to present evidence for their conclusions. When groups believe they have figured out the relative densities of the solutions, we ask them how they could provide succinct evidence for their thinking without having to cite multiple tests. Most groups create a test tube containing all four colored solutions, in layers. We ask students,

- *“What do you conclude about the densities of the solutions?"*
- *"How does your data support your conclusion?”*

We also ask,

- *“How does the fact that I did not tell you if you were correct relate to the way scientists gain confidence in their ideas?”*

Day 2

We start by revisiting students' findings from Day 1 by asking,

- *“What conclusion did you reach regarding the densities of these solutions?*”

Students sometimes come to different conclusions for a variety of reasons, including procedural error during the lab, careless note-taking or incorrect interpretation of their results. If this is the case, ask the students,

- *“How should we resolve this disagreement?”*

Encourage students to discuss their procedures and results. If necessary, send students back into the lab until they reach a consensus. When consensus has been reached, we say,

- *“Notice how you each collected evidence and came to your own conclusion based on this evidence. Now that you and your classmates have compared conclusions, how has your confidence in your conclusion changed?"*
- *"Notice you did not vote to determine the appropriate interpretation. How might your efforts to reach consensus be like how scientists reach consensus?"*
- *"Why is it so important that scientists don't simply vote on ideas?”*

In order to transition from the qualitative analysis on Day 1 into more quantitative experimentation, we ask students,

- *“Now that you're confident that you know the relative densities, what could you do to be more precise in your comparison of the solutions' densities?”*

If necessary, ask students,

- *“How might we be able to determine the numerical density of each solution?”*

This portion of the activity will require application of the equation for density (density = mass / volume), so students will need access to triple-beam balances and graduated cylinders. We ask students,

- *“Approximately how many times do you think you need to do each measurement in order to be confident in your results?”*

Encourage students to carefully record their data as they will need it for a challenge on the following day. Have students who finish early work on calculating the density of each solution. All students should complete these calculations before Day 3.

During Day 2, we must continue using extensive wait time and positive non-verbals to encourage student engagement. Students sometimes expect us to tell them what the procedure will be, but we want students to be thinking critically and creatively to devise the procedure. Yet, we are constantly moving around the room watching and listening to students. We carefully observe the room for both safety and cognitive concerns. When we see or hear students struggling, we use questions to scaffold their thinking. For example, a group of students might be struggling with the triple beam balance. Rather than simply show them what to do, we ask questions like,

- *“Why do we use the biggest mass first?"*
- *"How do we know when to use the smaller masses?"*
- *"Once the system is balanced, how do we determine the mass?”*

Day 3

To begin class, we ask the students to create a table on the whiteboard to compile their absolute density data for the four solutions they have tested. Draw students' attention to any outliers by asking questions like,

- *“What pattern, if any, do you infer in your data?”*

If additional scaffolding is needed, the following may be helpful:

- *“How consistent is your data?"*
- *"Which experimental values are farthest from the pattern you infer?"*
- *"How do you account for the data that falls farthest from the pattern you have inferred?"*

Students often want to discard data that doesn't appear to fit the pattern they have inferred, so we ask,

- *“What is your rationale for thinking this particular result may not be accurate?*

We use this opportunity to illustrate a key idea that scientists (and students!) assume that order exists in the natural world. To draw out this important idea, we ask questions such as,

- *“What assumption are you making about nature when you say this?"*
- *"How does this illustrate that scientists (and all of you!) assume nature behaves in a predictable manner?”*

Draw students' attention to their data for the absolute density of one solution and pose the following,

- *“Taking all your data into account for this solution, what do you think is the actual density of this solution?"*
- *"How does your decision reflect both the role of consensus in science and the fundamental assumption on which all of science is based – that order exists in the natural world?”*

A key point here is that we expect a single number to account for the density of each unknown liquid, and we interpret our data and reach consensus based on that expectation.

After this discussion, we challenge students to determine the density of an unknown solution of salt water using their procedures and the data they've collected up to this point. Ask students,

- *“Without making any quantitative measurements, how might you estimate the density of this unknown solution of salt water?”*

If students struggle with this task, guide them by asking questions that scaffold back to the method they used to determine relative densities on Day 1, and the absolute density data they determined on Day 2 (or agreed upon on Day 3). We encourage students to “check” their work by using both quantitative and qualitative methods by asking,

- *“What might be the benefit of using both relative and numerical procedures to determine the density?"*
- *"While we might prefer one procedure, how can we use both procedures to better support our conclusions?"*

While students work to determine the density of the unknown solution, we again circulate throughout the room to watch for safety concerns as well as guide students in their thinking. When students finish their analysis, we ask them to come to a consensus on the density of the unknown. Students have already reached consensus twice during this activity (regarding the qualitative and quantitative densities of the solutions), so this may be a fruitful opportunity to assess students' understanding of what consensus means and its role in authentic science research.

We begin a discussion to further students' conceptual understanding of density by asking,

- *“You have come to a consensus regarding the densities of these solutions. What do we really mean by density?”*

We work to use the students' ideas to drive the discussion toward the more abstract particulate view of density. Importantly, developing this idea is not easy, so this discussion could easily carryover to the next class period. Furthermore, predicting the nature of this discussion is difficult. While the specific discussions we have are highly nuanced and contextual, some questions we use to scaffold from students' experience in this activity to the abstract particulate idea include:

- *“What do these solutions contain?"*
- *"If you could look at this solution at an atomic/molecular level, what do you think you would see?"*
- *"Thinking back to how the solutions were layered in your test tubes, how would you explain the differences in densities on the particle level?”*

To help students make connections between their work and the abstract meaning of density, we ask students to place the following side-by-side:

1. Conclusions regarding the relative densities of the solutions.
2. Quantitatively determined density values.
3. Drawings of how the solutions compare at the atomic level.

Nature of Science Ideas Addressed in this Activity

This activity incorporates several opportunities to discuss nature of science (NOS) ideas. In particular, on Days 2 and 3 students are encouraged to come to consensus regarding the results of their investigations. After consensus is reached, students' attention is drawn through questioning to explicitly relate their experience to the way scientists come to accept new ideas.

On Day 1, questions are used to draw students' attention to the NOS idea that scientists collect evidence to build confidence in their ideas – there is no absolute authority figure to tell scientists if their ideas are accurate. Students' attention could also be drawn to how they must make sense of their data. That is, the data doesn't tell them what to think, they must make sense of the data – creating explanations that account for the data. Many students think science is not very creative, but helping them understand how scientists *create* explanations and methods confronts this misconception.

On Day 3, when students share their results from the previous day, students are asked to examine any outliers in the data on the board. When students suggest that some data is "wrong," questions are used to illustrate the NOS idea that scientists assume nature behaves in a predictable manner. This sharing of data is also an opportunity to draw students' attention to the role of communication and peers in science. Helping students understand the role of other people in their investigation can prevent students from seeing science as a lonely endeavor.

By explicitly illustrating NOS ideas throughout this activity, and asking questions that encourage students to compare their experience in class to how science works, students' understanding of both NOS and science content can be significantly deepened (McComas, Clough, & Almazroa, 1998).

The Teacher's Crucial Role

All lessons we teach, including those described here, are guided by a comprehensive set of goals we have for our students. Goals explicitly promoted through this activity include that students will:

1. *demonstrate a deep and robust understanding of fundamental science ideas.*
2. *exhibit an accurate understanding of the nature of science.*
3. *display critical-thinking and problem-solving skills.*
4. *exhibit creativity, curiosity, and a passion for learning.*
5. *communicate effectively.*
6. *use constructive social skills.*
7. *convey self-confidence and a positive self-image.*

Teachers who understand both how people learn and research-based strategies that promote deep mental engagement are in a far better position to effectively promote these goals (Clough, et. al., 2009). This inquiry activity reflects that learning is promoted by beginning with concrete experiences (directly observable layering of solutions) and then moving to abstract (how "tightly-packed" particles are in each solution). Abstract concepts are most deeply learned when the learner already has concrete experience from which to draw meaning (Karplus, 1977).

While this activity progresses from concrete to abstract descriptions of density, all aspects of the activity require students to have some prior understanding of this concept. For this reason, this activity was designed to take place in the application phase of the learning cycle, following exploration and development of the concept of density. The application phase is important in encouraging students to use their learning in new contexts (Karplus, 1977) – in this case, to qualitatively and quantitatively determine the densities of several solutions.

A teacher serves the crucial role of promoting student goals, in light of what we know about how people learn (Clough, Berg, & Olson, 2009). The teacher's role throughout this activity includes the use of thought-provoking questioning to encourage students to think deeply about the concepts involved and carefully scaffold students' initial ideas to the desired science understanding. These questions, coupled with extensive wait-time and inviting nonverbal behaviors, communicate to students that their ideas matter. Moreover, these behaviors can be used to scaffold students' thinking back to prior experiences in order to help them make more firm connections in their conceptual frameworks. We try to always carefully observe and listen to students while they conduct their investigations, as formative assessment of students' thinking is necessary for asking effective questions on the fly and in planning meaningful learning experiences in the future.

Final Thoughts

The inquiry approach used in this activity encourages students to take part in their own learning. We also want students' thinking and actions to align with the ways in which scientists develop their ideas. We accomplish this by spurring students to think of ways to qualitatively compare the densities of the solutions, support conclusions with evidence, quantitatively determine the density of each solution, and to come to a class consensus.

Inquiry involves more student-oriented learning, but students will not arrive at the big science ideas on their own. Instead, the teacher is crucial in mentally engaging students, drawing out students' thinking, and purposefully driving students to overcome misconceptions in order to develop a deep understanding of fundamental science content.

References

Clough, M.P., Berg, C.A., & Olson, J.K. (2009). Promoting Effective Science Teacher Education and Science Teaching: A Framework for Teacher Decision-Making. *International Journal of Science and Mathematics Education, 7*, 821-847.

Hardy, M., Jonen, A., Moller, K., & Stern, E. (2006). Effects of Instructional Support Within Constructivist Learning Environments for Elementary School Students' Understanding of Floating and Sinking. *Journal of Educational Psychology, 98*(2), 307-326.

Karplus, R. (1977). Science Teaching and the Development of Reasoning. *Journal of Research in Science Teaching, 14*(2), 169-175.

Kohn, A.S. (1993). Preschoolers' Reasoning about Density: Will it float? *Child Development, 64*(6), 1637-1650.

McComas, W.F., Clough, M.P., & Almazroa, H. (1998). The Role and Character of the Nature of Science in Science Education. Chapter 1. In McComas, W.M. (Ed.). *The Nature of Science in Science Education: Rationales and Strategies*. Dordrecht, The Netherlands: Kluwer.

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