This material is based upon work supported by the National Science Foundation under grants DRL-1814275 and DRL-1813254. This four-year project from 2018 to 2022 consists of the research and development of assessment instruments and instructional materials to support the development of elementary teachers' content knowledge for teaching about matter. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Content Knowledge for Teaching

The concept of matter is central to understanding many scientific ideas (NRC, 2012). While more is known about student learning relevant to matter, there is currently a lack of content-specific teaching knowledge about matter in the elementary years (Smith & Plumley, 2016). Therefore, this is an important area in which teacher educators can support the development of elementary teachers' content knowledge for teaching (CKT). CKT lives at the intersection of science content being taught and the Work of Teaching Science (WOTS).

Educative Curriculum Materials

Curriculum materials are a means of supporting teacher learning (Ball & Cohen, 1996; Davis & Krajcik, 2005), and educative curriculum materials (ECM) are specifically designed to help develop knowledge to improve instructional decision making (Davis & Krajcik, 2005). Our conjecture is that educative curriculum materials for teacher educators might similarly support teacher educator and preservice teacher learning and could support the development of CKT about matter and its interactions in teacher education.

Our Work

In our project, we ask, *How might curriculum materials be designed and implemented to support teacher educator and preservice teachers' learning?*

We have been engaged in a theoretically and empirically-grounded design process (Davis et al., 2014) to develop ECM for teacher educators related to CKT about matter and its interactions. In this poster, we share our design heuristics, and examples of educative features included in the suite of CKT Packets we developed. To date, we have developed six sets of materials, with two more in development (see Table).

CKT Packets have undergone several rounds of feedback, pilot implementation, and review. As a next step in our work, we will be using a quasi-experimental cohort-control design to conduct an implementation study in order to examine the use of the materials by teacher educators and the impacts on preservice teachers' CKT.

For more information about this project and to sign up for access to our educative curriculum materials and other resources, visit http://cktscience.org

Work of Teaching Science Instructional Tools

Content	Instructional Goals, Big Ideas, and Topics	Scientific Resources	Scientific Models & Representations	Student Ideas	Scientific Language And Discourse	Scientific Explanations	Scientific Investigations & Demonstrations
Materials	Piloted						
Properties of matter		Under development			Under development		
Model of matter			Piloted	Piloted			
Changes in matter						Piloted	Piloted
Conservation of matter							Piloted

Design Heuristic #1: Supporting Teacher Educators in Engaging Preservice Elementary Teachers in the Work of Teaching Science

- Highlight the work of teaching science and provide rationales for why this work is important.
- Help teacher educators adapt and use resources with their preservice teachers in pedagogically appropriate ways, for example:
  - by making explicit how specific science teaching practices correspond to different concepts and ideas
  - providing recommendations for how those might be introduced in different contexts and courses.

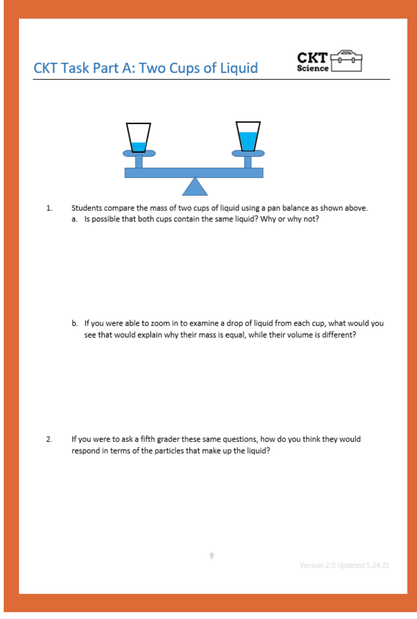
Design Heuristic #2: Supporting Teacher Educators in Anticipating, Understanding, and Addressing Preservice Elementary Teachers' Ideas about Science and Science Teaching

- Help teacher educators understand how preservice teachers develop CKT for science.
- Support teacher educators in anticipating, eliciting, and interpreting preservice teachers' ideas.
- Provide insight into how teachers educators might address those ideas in their teaching, for example by giving suggestions of tools and activities to confront preservice teachers' initial ideas about teaching science in productive ways.

Design Heuristic #3: Support Teacher Educators in the Development of Preservice Teachers' Content Knowledge

- Provide teacher educators with tools for helping preservice teachers develop a deep conceptual understanding of science content as a foundation for building CKT.
- Help teacher educators support preservice teachers assess their own content ideas and understand why strong content knowledge is important for teaching.
- Key differences between the understanding required of preservice teachers and their students are emphasized.

Examples of Educative Features included in CKT Packets


CKT Task Part A: Two Cups of Liquid

CKT Science

1. Students compare the mass of two cups of liquid using a pan balance as shown above.
   a. Is possible that both cups contain the same liquid? Why or why not?
   b. If you were able to zoom in to examine a drop of liquid from each cup, what would you see that would explain why their mass is equal, while their volume is different?
2. If you were to ask a fifth grader these same questions, how do you think they would respond in terms of the particles that make up the liquid?

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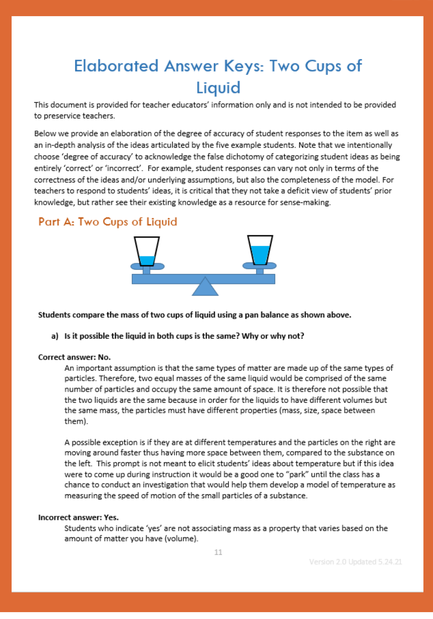
Elaborated Answer Keys: Two Cups of Liquid

This document is provided for teacher educators' information only and is not intended to be provided to preservice teachers.

Below we provide an elaboration of the degree of accuracy of student responses to the item as well as an in-depth analysis of the ideas articulated by the five example students. Note that we intentionally choose 'degree of accuracy' to acknowledge the false dichotomy of categorizing student ideas as being entirely 'correct' or 'incorrect'. For example, student responses can vary not only in terms of the correctness of the ideas and/or underlying assumptions, but also the completeness of the model. For teachers to respond to students' ideas, it is critical that they not take a deficit view of students' prior knowledge, but rather see their existing knowledge as a resource for sense-making.

Part A: Two Cups of Liquid

Students compare the mass of two cups of liquid using a pan balance as shown above.

a) Is it possible the liquid in both cups is the same? Why or why not?

Correct answer: No.
An important assumption is that the same types of matter are made up of the same types of particles. Therefore, two equal masses of the same liquid would be comprised of the same number of particles and occupy the same amount of space. It is therefore not possible that the two liquids are the same because in order for the liquids to have different volumes but the same mass, the particles must have different properties (mass, size, space between them).

A possible exception is if they are at different temperatures and the particles on the right are moving around faster thus having more space between them, compared to the substance on the left. This prompt is not meant to elicit students' ideas about temperature but if this idea were to come up during instruction it would be a good one to "park" until the class has a chance to conduct an investigation that would help them develop a model of temperature as measuring the speed of motion of the small particles of a substance.

Incorrect answer: Yes.
Students who indicate 'yes' are not associating mass as a property that varies based on the amount of matter you have (volume).

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Preparing for Implementation

This task assumes that preservice teachers already have some prerequisite content knowledge about matter, and pedagogical understanding of what is meant by 'scientific model' and the scientific practice of 'modeling'. Support is provided for distinguishing between 'teaching models' and 'scientific models'; however, preservice teachers who have not been formally introduced to models and modeling may need additional learning experiences prior to engaging in this task.

NGSS Alignment

This task most closely relates to the following NGSS performance expectation for elementary students:

5-PS1-1. Develop a model to describe that matter is made of particles too small to be seen.

According to the Framework, by the end of grade 5, elementary students should understand that matter of any type can be subdivided into particles that are too small to see, but even then the matter still exists and can be detected by other means (e.g., by weighing or by its effects on other objects). At this grade level, no attempt is made to define the unseen particles—which is an important consideration for preservice teachers, who as adults have likely developed a model that includes entities such as molecules, atoms, and various subatomic particles.

This particular Performance Expectation builds on what elementary students learn in 2nd grade about properties of matter, in that the SPM can be used to explain differences in the properties and behavior of solids, liquids, and gases, and how matter can change from one form to another (e.g., evaporation).

Content Focus: Small Particle Model (SPM)

This sub-area of the content focuses on developing and using a particle model of matter to explain properties and behavior of solid, liquids, and gases. The model is developed from the observation and description of macroscopic properties, for example, the particle model can be used to explain how liquids and gases do not have a shape of their own, but conform to their containers.

In grades K-2, matter is modeled using objects, such as building blocks. Objects made of pieces can be disassembled and reassembled into new objects with different characteristics (e.g., size, shape, arrangement of pieces). However, the properties of the pieces themselves remain the same. In grades 3-5, particle models are used to describe and explain the behavior of bulk matter.

Observable phenomena, such the effects of wind on objects, inflating a balloon, or sugar dissolving in water, provide evidence that matter is made of particles that are too small to be seen. At this grade level, instruction does not include creating and using models to explain atomic-scale mechanisms of evaporation and condensation, or defining the invisible particles (i.e., as atoms, molecules, or ions).

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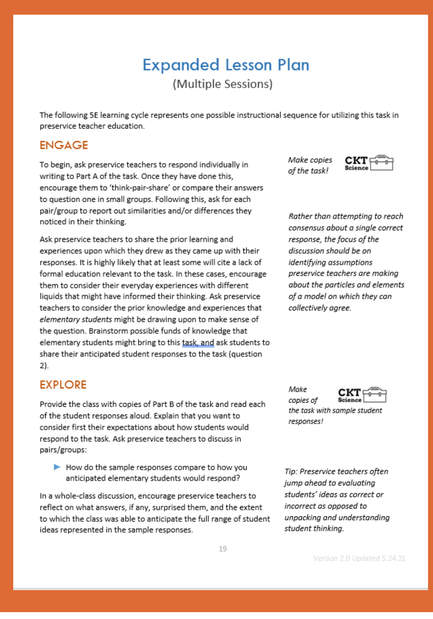
Expanded Lesson Plan
(Multiple Sessions)

The following 5E learning cycle represents one possible instructional sequence for utilizing this task in preservice teacher education.

ENGAGE

To begin, ask preservice teachers to respond individually in writing to Part A of the task. Once they have done this, encourage them to 'think-pair-share' or compare their answers to question one in small groups. Following this, ask for each pair/group to report out similarities and/or differences they noticed in their thinking.

Make copies of the task!

Ask preservice teachers to share the prior learning and experiences upon which they drew as they came up with their responses. It is highly likely that at least some will cite a lack of formal education relevant to the task. In these cases, encourage them to consider their everyday experiences with different liquids that might have informed their thinking. Ask preservice teachers to consider the prior knowledge and experiences that *elementary students* might be drawing upon to make sense of the question. Brainstorm possible funds of knowledge that elementary students might bring to this task, and ask students to share their anticipated student responses to the task (question 2).

Rather than attempting to reach consensus about a single correct response, the focus of the discussion should be on identifying assumptions preservice teachers are making about the particles and elements of a model on which they can collectively agree.

EXPLORE

Provide the class with copies of Part B of the task and read each of the student responses aloud. Explain that you want to consider first their expectations about how students would respond to the task. Ask preservice teachers to discuss in pairs/groups:

- How do the sample responses compare to how you anticipated elementary students would respond?

Make copies of the task with sample student responses!

In a whole-class discussion, encourage preservice teachers to reflect on what answers, if any, surprised them, and the extent to which the class was able to anticipate the full range of student ideas represented in the sample responses.

Tip: Preservice teachers often jump ahead to evaluating students' ideas as correct or incorrect as opposed to unpacking and understanding student thinking.

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ADDITIONAL RESOURCES

Options for Going Further

Note: Many preservice teachers might believe an appropriate pedagogical response to elementary students' ideas is to provide students with the 'correct' small particle model of matter. While this is not a focus of this particular task, we have included the distinction between students' modeling and teachers using models as teaching tools in the Reading Page: *Scientific Models* should you wish to extend the class discussion to address that idea.

To further extend preservice teachers' learning, we recommend having them:

- Interview an elementary student using the task, and provide an analysis and evaluation of the student's ideas.
- Evaluate an activity (in the form of lesson plan, article from practitioner journal, etc.) in terms of the extent to which it effectively elicits students' ideas and/or offers appropriate responses to those ideas (see note above)
- Evaluate the strengths and limitations of a teaching model (simulation, representation, etc.) of the small particle model of matter
- Participate in a 'model lesson' about matter while taking the perspective of one of the five students in the sample responses. (See Additional Resources for possible lessons.)
- Identify another scenario (similar to the cups or cubes) that might help elicit students' understanding of the small particle model of matter.

Related Research

The following articles helped inform the development of these materials and can enhance your own understanding and ability to support preservice teachers' CKT about matter.

Kokkotas, P., Vlachos, I., & Koulaidis, V. (1998). Teaching the topic of the particulate nature of matter in prospective teachers' training courses. *International Journal of Science Education, 20*(3), 291–303.

Nakhleh, M. B., & Samarapungavan, A. (1999). Elementary school children's beliefs about matter. *Journal of Research in Science Teaching, 36*(7), 777–805.

Schwarz CV, Reiser BJ, Davis EA, et al. (2009) Developing a Learning Progression for Scientific Modeling: Making Scientific Modeling Accessible and Meaningful for Learners. *Journal of Research in Science Teaching* 46: 632-654.

Smith, P. S. & Plumley, C. L. (2016). *A review of the research literature on teaching about the small particle model of matter to elementary students.* Chapel Hill, NC: Horizon Research, Inc. Available: http://www.horizon-research.com/spmlitreview

Tsaparlis, G., & Sevian, H. (2013). *Concepts of Matter in Science Education* (Vol. 19). Dordrecht: Springer. https://doi.org/10.1007/978-94-007-5914-5

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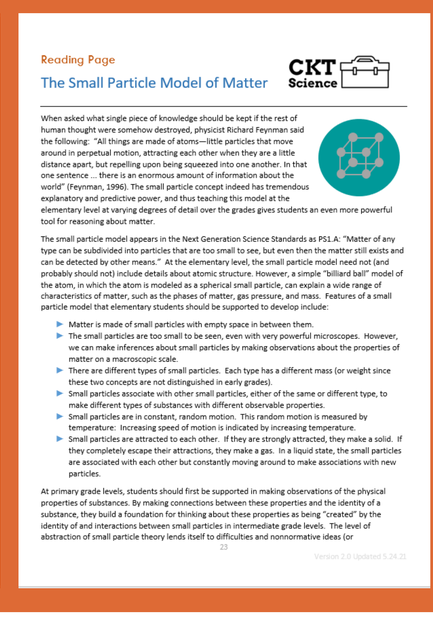
Reading Page

The Small Particle Model of Matter

CKT Science

When asked what single piece of knowledge should be kept if the rest of human thought were somehow destroyed, physicist Richard Feynman said the following: "All things are made of atoms—little particles that move around in perpetual motion, attracting each other when they are a little distance apart, but repelling upon being squeezed into one another. In that one sentence … there is an enormous amount of information about the world" (Feynman, 1996). The small particle concept indeed has tremendous explanatory and predictive power, and thus teaching this model at the elementary level at varying degrees of detail over the grades gives students an even more powerful tool for reasoning about matter.

The small particle model appears in the Next Generation Science Standards as PS1.A: "Matter of any type can be subdivided into particles that are too small to see, but even then the matter still exists and can be detected by other means." At the elementary level, the small particle model need not (and probably should not) include details about atomic structure. However, a simple "billiard ball" model of the atom, in which the atom is modeled as a spherical small particle, can explain a wide range of characteristics of matter, such as the phases of matter, gas pressure, and mass. Features of a small particle model that elementary students should be supported to develop include:

- Matter is made of small particles with empty space in between them.
- The small particles are too small to be seen, even with very powerful microscopes. However, we can make inferences about small particles by making observations about the properties of matter on a macroscopic scale.
- There are different types of small particles. Each type has a different mass (or weight since these two concepts are not distinguished in early grades).
- Small particles associate with other small particles, either of the same or different type, to make different types of substances with different observable properties.
- Small particles are in constant, random motion. This random motion is measured by temperature: Increasing speed of motion is indicated by increasing temperature.
- Small particles are attracted to each other. If they are strongly attracted, they make a solid. If they completely escape their attractions, they make a gas. In a liquid state, the small particles are associated with each other but constantly moving around to make associations with new particles.

At primary grade levels, students should first be supported in making observations of the physical properties of substances. By making connections between these properties and the identity of a substance, they build a foundation for thinking about these properties as being "created" by the identity of and interactions between small particles in intermediate grade levels. The level of abstraction of small particle theory lends itself to difficulties and nonnormative ideas (or

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CKT Tasks - elicit preservice elementary teachers' understanding of the WOTS (Heuristic 1) and the content (Heuristic 3) relevant to the CKT focus.

Elaborated Answer Keys - provide example preservice teacher responses and possible reasoning to help teacher educators analyze responses (Heuristic 2).

CKT Overviews - provide information about teaching practices (Heuristic 1) and NGSS alignment (Heuristic 3) relevant to the CKT focus.

Suggested Lesson Plans - (Heuristic 2) provide guidance. **Call-outs** on right bring attention to specific teaching moves to highlight WOTS (Heuristic 1) or content understanding (Heuristic 3).

Additional Resources - support teacher educator and preservice teachers' learning about the WOTS (Heuristic 1) and content (Heuristic 3) relevant to the CKT focus.

Reading Pages - support preservice teachers' WOTS understanding (Heuristic 1) and content knowledge (Heuristic 3) for CKT development.

References

1. National Research Council. (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. Board on Science Education. Washington, DC: National Academies Press.
2. Smith, P. S., & Plumley, C. L. (2016). A Review of the Research Literature on Teaching about the Small Particle Model of Matter to Elementary Students. Horizon Research, Inc.
3. Ball, D. L., & Cohen, D. K. (1996). Reform by the book: What is—or might be—the role of curriculum materials in teacher learning and instructional reform? Educational Researcher, 25(9), 6-14.
4. Davis, E. A., & Krajcik, J. S. (2005). Designing educative curriculum materials to promote teacher learning. Educational Researcher, 34(3), 3-14.
5. Davis, E., Palincsar, A. S., Arias, A. M., Bismack, A. S., Marulis, L., & Iwashyna, S. (2014). Designing educative curriculum materials. Harvard Educational Review, 84(1), 24-52.