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Building Theories by Building Things

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Abstract

In the science classroom, curriculum often engages students in science experiments with predetermined materials and scaffolded instructions in order to obtain a designated outcome. However, science experiments like this focus on the product of experiment but not the process of designing an experiment. Implicit in these labs is that the goal of the science classroom is to learn specific scientific content instead of learning how to build theories and develop experiments in support of those. If, instead, we want science classes that support students in developing, vetting and refining theories, our research suggests that increased student agency around materials and design is critical. As students make design choices in their experiments, they enter into a conversation with materials and design and these inform and shape their developing models in richly scientific ways. Through the use of student examples we will show how students can use materials in novel and authentic ways that improve their design practice and solidify their scientific theories.

Building Theories by Building Things

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The EDISIn Project: Engineering Design in Scientific Inquiry

Most science standards, at the state and national level, include engineering design as one of the core scientific practices as a way for students to do science. The EDISIn research project focuses on identifying when opportunities for engineering design authenticity emerge during scientific inquiry. From this research, we hope to inform the science curriculum by more seamlessly incorporating engineering design in a scientific context into the science classroom.

Research Questions

How do students use materials in the science classroom?

- How do students use materials as they develop scientific ideas?
- What role does material agency (the ability to manipulate and modify materials as needed) play in experimental design?

What role do those materials play in theory development?

- Do students use materials to build theory, to test/apply theory, as demonstration of theory, or something else?

The Course

Data is collected from STEM-Ed 350: Research Methods course which is a part of the IDoTeach program, and focuses on providing an opportunity for pre-service science teachers to engage in scientific research as a part of their coursework. For the Spring 2021 class, they were focused on the topic of light and color and would spend the semester dissecting the question; is every color in the rainbow?

Picture showing different colored gel filters that the students used to explore light and color.

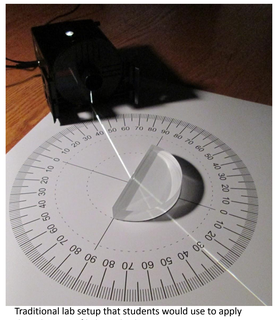
The Role of Materials in the Science Classroom

Case Study: Color

The Problem

Often in science classrooms, we see students using materials only as a means to reach a designated outcomes. Students are told how to use materials, usually in the form of an experiment, where the design of the experiment has been pre-fabricated and thought out for them. Students simply follow the instructions given to them, set up the materials allocated to them, and hope to achieve the "correct" experimental results without any thought to why they are setting up the experiment in this manner.

This picture (right) represents what a traditional lab setup would look like for students who are studying light, color, and optics. Students would set up this experiment to apply the theories they have already learned about color and light. Having no consideration for why they are using these particular materials or how this experimental design has changed over time.

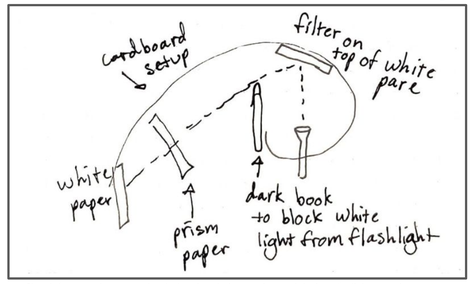


Traditional lab setup that students would use to apply their theories of light and color.

If pre-designed labs are not authentic to scientific inquiry or conducive to scientific theory building, then why do we have students do them? One could argue that with the speciality lab equipment that students use they can produce more accurate data, and more aesthetically pleasing graphs. Or maybe it is just in the name of scaffolding for students, for producing uniformity, or simply due to time constraints and the need to cover large amounts of science content. However, having students engage in these pre designed labs comes at a cost to the students.

So what happens when we give students materials and have them use the materials to building things, while also building scientific theory?

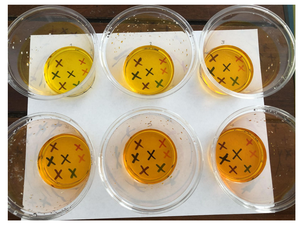
Finally, we see the final version of a student's experiment in the sketch below. In this sketch we see the thoughtful design choices that have been made after many alterations and iterations of this experiment. These choices include the spiral shape of the cardboard and the placement of a dark book to block the light. All of these choices were made as an improvement to the experimental design, and it was through the process of building this experiment that the students were able to build scientific theory. The new scientific theories that these students built not only expanded their model of light and color but the whole classes model of light and color.



Sketch from student's notebook showing their experimental design of a light experiment.

A student exploring their materials by creating different concentrations and color combinations with printer inks.

When you give students unfamiliar materials, or even just materials that you wish for them to modify to build something with, the students must first be allowed to tinker and discover with the materials. For example, in this picture above we see a student exploring the properties of four different colors of printer inks and discovering how varying the concentration of the inks produces different colors.



A student creates a simple experiment with yellow printer ink and colored markers to see how the marker colors change when viewed through the ink.

Once students become more familiar with the materials, then they begin modifying the materials to produce simple science experiments that test their scientific knowledge. Like we see above, this student has began using the materials of printer inks and colored markers to test the model that printer inks can act like gel filters eliminating certain colors and changing the appearance of other colors. When students start creating simple experiments and testing their knowledge, they also start constructing new scientific theories.

A student's experiment using household materials like books cardboard, and flashlights to create a design that can test their scientific theory.

As students develop more complex scientific theories, the experiments needed to test these theories also become more complicated requiring elaborate materials and many iterations of the experiments. It is through these iterations, and subsequent alterations to the experiment design that allow students to build and solidify scientific theory. In the picture above, we see two student's experiment built to test the theory that light reflects off of gel filters. After many modifications, the students were able to come up with a spiral shape design and a light blocking apparatus (a book). It was through these changes to the experimental design that the students built the most scientific theory.

Acknowledgements

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References

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Claims

Student should be allowed to develop their own scientific theories

- The process of building scientific theory is just as important as the product. By allowing students to engage in the process of theory development, supported by the use of materials, students are able to employ scientific practice to grow their scientific knowledge.

This requires agency with materials: to build scientific theory, students need to build things.

- Students need to have unscripted experiences with materials where they can freely create and design. It is this creative and iterative design process of building things that allows to students to expand their ideas and build scientific theory.

Conclusion

Today's science classrooms are using materials and scientific experiments as a way to support the application of scientific theory. We see students being given labs with predetermined outcomes, scaffolded instructions, and carefully selected materials with no creativity, which does not replicate activities of practicing scientists. Science classrooms are supposed be creative, fun, and inspiring places where students can thoughtfully engage in the work of scientific inquiry. By giving students the opportunity to explore this creative space and work through the process of designing a scientific experiment, student can also expand their ideas and develop their own scientific theories.

Implications

- Students should have agency around materials, and be provided experiences that allow them to explore and create with materials.
- It takes time to develop a well-designed experiment. Students need to tinker, alter, refine, and change their design over time to produce a functional experiment.
- Students should be provided opportunities to create iterations of their designs. Experimental design emerges over time as feedback from design choices cause changes and students' scientific ideas improve.