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Teacher's Toolkit: Differentiating Inquiry

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Differentiating inquiry

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Differentiated instruction and teaching science as inquiry are two pedagogical approaches frequently discussed among science teachers. Teachers know these approaches are important but often have difficulty translating them into their classroom science instruction. This article describes how to differentiate a density investigation for variations in student readiness by varying the level of inquiry using an approach that is easily translated to experiments in any science content area.

Levels of inquiry

Inquiry can be defined in a practical and accessible way as "an active learning process in which students answer research questions through data analysis" (Bell, Smetana, and Binns 2005, p. 35). This straightforward definition of inquiry is easy for teachers to understand. Bell, Smetana, and Binns (2005) also describe four levels of inquiry based on the amount of guidance given to students: confirmatory, structured, guided, and open. In confirmatory inquiry, students are given a question and procedure, which they use to confirm a previously learned relationship or principle. In structured inquiry, the question and procedure are provided to students, but they do not know the outcome of the investigation in advance of the activity. Guided inquiry only provides students with the research question; they develop their own procedure to answer it. In open inquiry, students develop their own question, create their own procedure, and, through data analysis, discover the solution to their research question. In this activity, levels of structured, less structured, and guided inquiry are provided for use.

To have an opportunity to develop scientific practices such as asking questions, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, and constructing explanations (NRC 2012), students should be provided with scaffolded opportunities to experience inquiry at each of these levels. Ideally, teachers should use inquiry activities that move students along a continuum toward doing open inquiry. Therefore, it is important for the teacher to provide support and opportunities for students to practice inquiry with the goal of facilitating them in conducting higher levels of inquiry (Bell, Smetana, and Binns 2005). Differentiation is one way to provide this support to students.

Differentiation

Differentiation is a way of thinking about learning and teaching that addresses differences in students' learning needs (Tomlinson and Imbeau 2010). According to Lorna Earl, "Differentiation is making sure that the right students get the right learning tasks at the right time" (2003, p. 86). As described by Tomlinson and Imbeau (2010, p. 27–36), differentiation is based on six beliefs:

1. Every student is worthy of dignity and respect.
2. Diversity is both inevitable and positive.
3. The classroom should mirror the kind of society in which we want our students to live and lead.
4. Most students can learn most things that are essential to a given area of study.
5. Each student should have equity of access to excellent learning opportunities.
6. A central goal of teaching is to maximize the capacity of each learner.

These beliefs guide how teachers structure learning activities for students and interact with them in the classroom. They should lead teachers to invite students to learn with them and let students know that they are willing to invest in them as individuals. The beliefs ask teachers to show persistence in encouraging students toward growth and provide opportunities for students to reflect on their learning. Thus, the philosophy of differentiation has the potential to shape a teacher's curriculum and instruction to be supportive, engaging, challenging, and focused (Tomlinson 2003).

The philosophy of differentiation is a way of thinking, but in order for it to facilitate student growth, it must be implemented effectively in the classroom. Teachers do this through consideration of students' varied learning needs with regard to readiness, learning profile, and interest when planning instruction. *Readiness* refers to a student's knowledge and skills as they pertain to academics. *Learning profile* is a student's gender, culture, learning style, and intelligence preference. *Interest* is characterized by topics and pursuits that appeal to a student's curiosity (Tomlinson 2003).

In differentiating instruction, it is imperative for teachers to also consider five interdependent aspects of classroom systems and how they are related to the aforementioned student needs: learning environment, curriculum, assessment, classroom leadership or management, and instruction (Tomlinson and Imbeau 2010). Effective differentiated instruction first creates a learning environment where students feel "safe, respected, involved, challenged, and supported" (Tomlinson and Imbeau 2010, p. 20). Second, the curriculum must be of high quality and require students to engage with the essential knowledge, understandings, and skills for the lesson or unit (Tomlinson and Imbeau 2010). It is critical that the activities within lessons be aligned with the lesson goals, otherwise it will be difficult to determine if students have successfully met those goals. Third, differentiation emphasizes the use of pre-, formative, and summative assessment (Tomlinson and Imbeau 2010). Assessments inform the teacher of students' readiness, interests, or learning profiles and aid the teacher in determining how to move forward with future instruction. Fourth, classroom leadership or management must be in place for instruction to be effective. Without this aspect, neither inquiry nor differentiation is possible. Teachers must create an environment where differentiation is understood and accepted by students from the beginning of the year. Finally, the instruction, or the delivery of the curriculum, must align with the goals for the lesson or unit and lead students to deeper understanding by accounting for student differences (Tomlinson and Imbeau 2010). All five of these aspects are critical to successful differentiation in the classroom.

In practice, differentiation occurs when teachers respond to students' needs by differentiating students' access to the content, the process by which students learn, or the product of learning according to students' readiness, interests, or learning profiles (Tomlinson 1999). One strategy that allows a teacher to differentiate based on student readiness is tiering. In tiered lessons, the same content and learning goals are addressed but

FIGURE 1 **Example of a formal preassessment of scientific-practices skills and density**

1. The volume of a liquid is typically measured using a

   a. balance.

   b. graduated cylinder.

   c. thermometer.

   d. beaker.

2. A paper clip has a mass of approximately

   a. 1 mg.

   b. 1 g.

   c. 1 kg.

   d. 1 Mg.

3. The independent variable is

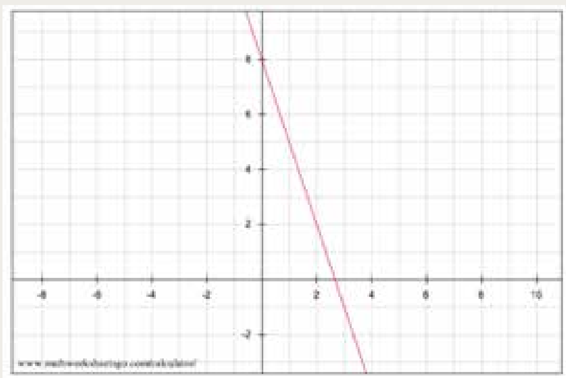
   a. always graphed on the *y*-axis.

   b. always graphed on the *x*-axis.

   c. always graphed on the *z*-axis.

   d. never graphed.

4. Determine the slope of the line. Please show your work.



5. Explain, using words or pictures, what density is.

6. If you were given a solid object, describe how you would find its density.

FIGURE 2 Structured-inquiry handout (tier 1)

Density lab

Research question
Does the density of an element change?

Purpose
In this experiment, you will measure the mass and volume of several elements, then calculate and graph their densities.

Materials

- Element samples
- Graduated cylinder
- Scale
- Ruler

Procedure

1. Obtain three sizes of *each* element from the basket. Do not mix up the elements (A, B, C).
2. Use the water displacement technique to measure the volume of each object. To do this you do the following:
    a. Fill a 25 or 50 mL graduated cylinder with enough tap water to cover the object, but do not add the object yet. Record the volume of the water as the "before volume" (the volume of the water only) in the table to the right.
    b. Tilt the graduated cylinder slightly and gently slide the object down the side of the cylinder. DO NOT drop it in, as this may break the glass or cause the water to splash.
    c. Record the volume of the water and with the object inside as the "after volume" (the volume of the water and the object) in the table.
    d. Calculate the volume of the object only (after volume – before volume = volume of the object only) and record it in the table.
    e. Remove the object and repeat the volume process with each of the other objects.
3. Measure the mass of each object by using one of the balances in the room and record it in the table. Make sure all of the objects are dry before you mass them.

Data

Sample	Before volume / volume of water only (mL)	After volume/ volume of water and object (mL)	Total volume/ volume of object only (mL)	Mass (g)
Element A, sample 1				
Element A, sample 2				
Element A, sample 3				
Element B, sample 1				
Element B, sample 2				
Element B, sample 3				
Element C, sample 1				
Element C, sample 2				
Element C, sample 3				

Analysis (calculations)

1. What is the formula for calculating density?
2. Use the formula for density and *one* data point for each element to calculate the density of each of your elements. Show your work for each calculation.

Analysis (graphing)

1. Taking your data from above, record them in the table below. You will not have any data in the gray boxes.

Total volume/ volume of object only (mL)	Mass—Element A (g)	Mass—Element B (g)	Mass—Element C (g)

2. Open Logger Pro and enter the data for Element A into your data table. Remember that you will need to change your *x* and *y* labels, short name (V_a for total volume A, and m_a for mass A), and units to the correct ones.
3. To enter the data for Element B and Element C, choose "Data" and then "New Manual Column." Do this twice so that you have four columns. You will see new columns appear. Change the label, short name, and units, appropriately. Enter your data as you have above; where there are gray boxes you should have empty boxes.
4. Change the size of your table so that all of the columns can be seen. Then change the size of the graph, as well, so all of it can be seen.
5. Change what is being graphed so that on the *y*-axis the masses for A, B, and C are graphed.
6. Choose "Analyze" and then "linear fit" and select all three of your mass columns. You should see three boxes appear on your graph. Move the boxes so you can identify which box goes with which line.
7. Print your graph.
8. From your graph, write the equation of each line and the slope to get the density of each element (slope = m = density).

Analysis (questions)

1. How did the density of each element compare when you used the graphing approach and the single-data-point calculation of density? Which do you think is more precise? Why?
2. *Challenge:* Using your book or an online reference, try to identify each material based on its physical properties and your calculated density. Cite the sources used below.
3. Ask your teacher for the actual density of each element and calculate the percentage error in your lab data, using the density from the graph, for each sample. Show your work.

Conclusions

1. What could you have changed about the experiment to lower your error?
2. Does the density of an element change? How do you know?
3. What did you learn about calculating the density of a metal?
4. Based on what you learned about how density is calculated, describe another way you could determine the density of a solid object.
5. Explain, using words or pictures, what density is.
6. Did everyone in the class use the same method to complete the lab? What does that tell you about science?

the teacher provides students with activities of different degrees of complexity or abstractness in order to challenge individual students at their point of readiness. As a result, students are able to work at appropriate challenge levels and have a successful learning experience (Tomlinson 1999). An example of this approach to differentiation is outlined below in the context of a density investigation tiered to address students with different mastery levels of science process skills.

Tiered inquiry activity to teach density

In this tiered activity, all students complete an inquiry activity related to the science concept of density. Each investigation in the tiered activity uses the same materials but varies in the inquiry level or support provided to students. In the *Next Generation Science Standards*, this would fit under the crosscutting concept of patterns and the disciplinary core idea of PS1.A: Structure and Properties of Matter. This activity helps students investigate density as one of the characteristic physical and chemical properties of a pure substance (MS-PS1-2). Students are able to engage in the scientific practices of asking questions, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, and constructing explanations (Achieve Inc. 2013).

Assessing students' prior knowledge

Since this activity is tiered based on student readiness, students should be grouped with similar-readiness peers. This grouping is based on a formative assessment of students' mastery of targeted science practices, including asking questions, planning and carrying out investigations, analyzing and interpreting data, using mathematics and computational thinking, and constructing explanations (NRC 2012). This preassessment may be informal (e.g., based on observation of students prior to the activity) or formal (e.g., a brief quiz given the day before the activity [Figure 1]). Based on their response to the preassessment and the teacher's prior knowledge of their inquiry skills, students are placed in one of three groups (structured, less structured, and guided). Subdivide these groups into smaller lab groups (we recommend three to four students per group).

Introducing the activity

Start the lesson through a conceptual review of density and its determination. We recommend a demonstration in which the teacher masses a fishbowl with only water, a fishbowl with sand and water, and a fishbowl with marbles, sand, and water. When conducting the demonstration, ask students which quantity remains the same (volume) and which quantity changes (mass) in each of the situations. Use questioning to guide students to understand that the density of each fishbowl is different. Students' responses to the teacher's questions will help to illuminate students' misconceptions prior to beginning the activity.

Next, the teacher introduces the question that is the focus of the lesson: Does the density of an element change? After introducing students to this question, the teacher provides each readiness group the appropriate handout (Figures 2, 3, and 4). Students should be able to answer this question using the data they collect.

Conducting the investigation

To conduct their experiments, students need several different massed samples of three readily available and nonhazardous elements (e.g., aluminum, zinc, and copper). A common option is lead fishing weights; however, if you choose to use lead in the investigation, make sure students wear gloves to ensure safety when handling it.

When planning for tiered lab activities, note that each tier will need slightly different instructions. It is important to consider how to effectively and efficiently provide these directions. We recommend including very detailed directions on the lab handouts for tiers 1 and 2. First, orally give general directions that pertain to all groups (e.g., how to use the Logger Pro software to graph data), then have students in tier 3 begin working on their procedure. This allows the teacher to spend more time up front clarifying directions to students working in tiers 1 and 2 and then review tier 3 students' procedures. Each group may need different amounts of instruction for completing the handout, so it is important to consider how you will approach the start of the activity prior to instruction.

Students grouped into tier 1 complete a structured-inquiry investigation (Figure 2). In this version of the activity, students are given the question, the procedure to complete the experiment, the data to collect, a data table, and directions on how to graph the data and complete the analysis. They are also provided the actual densities of the elements so they can calculate the percentage error. This version of the investigation provides ample support to students who struggle with

FIGURE 3 Less-structured-inquiry handout (tier 2)

Density lab

The research question, purpose, materials, procedure, and analysis (calculations) are repeated from Figure 2, the structured-inquiry handout.

Data
Create a data table to record the data you collect.

Analysis (graphing)
Using your collected data, create a graph using Logger Pro. Graph the volume on the *x*-axis and the mass on the *y*-axis. When you are finished graphing, you should have three lines, one for Element A, one for B, and one for C. Print your graph. From your graph, write the equation of each line. Use the slope to get the density of each element (slope = m = density).

The analysis (questions) and conclusions are repeated from Figure 2, the structured-inquiry handout.

FIGURE 4 Guided-inquiry handout (tier 3)

Density lab

The research question, purpose, and materials are repeated from Figure 2, the structured-inquiry handout.

Procedure
Write the steps you will follow to complete the lab. Get this approved by your teacher before beginning.

Data
Create a data table to record the data you collect.

Analysis (calculations) and analysis (graphing) are repeated from Figure 3, the less-structured-inquiry handout. The analysis (questions) and conclusions are repeated from Figure 2, the structured-inquiry handout.

developing procedures, determining which data are appropriate to collect, and organizing data, allowing them to focus on data collection, graph creation, and data analysis without being consumed with these process skills.

Students who need support in developing a procedure but can readily interpret and analyze data complete a less scaffolded version of the structured-inquiry activity described above. These students, in tier 2, are given the question and procedure and told which data to collect. These students receive some support by being given the procedure for data collection; however, they are not given a data table or directions on how to organize their data, graph their data, or complete their analysis (Figure 3).

Tier 3 students complete a guided-inquiry activity in which they are only given the research question. They develop a procedure to answer the research question, determine which data to collect, create a data table, graph their data, and complete the analysis on their own (Figure 4). Guided inquiry requires greater independence and understanding of science process skills and provides students with an activity involving greater complexity and abstractness.

Regardless of the tier, after completing this investigation, all students should understand that density of a substance does not change. Students come to this understanding by graphing the densities and recognizing that the slope of the line for each element is constant. The teacher may also choose to address that density can change with temperature or pressure depending on students' background knowledge. This will also connect to the following mathematics *Common Core State Standards*: MP.2, 6.RP.A.3, 6.SP.B.4, and 6.SP.B.5 (NGAC and CCSSO 2010).

Assessing the activity

When they have completed the investigation and answered the analysis and conclusion questions, bring the small groups back together for a whole-class discussion. During this time, students share their responses to conclusion questions and the results of their investigations. Students' oral and written responses to the analysis and conclusion questions serve as a means for the teacher to assess students' understanding of the concepts. It is also an opportunity for the teacher to revisit and readdress any misconceptions that may remain.

Assessment of tiered activities can be a challenge in classrooms where the teacher has not previously addressed the underlying philosophical assumptions of differentiation, that "fair" does not necessarily mean "the same," and that differentiated activities are designed to provide opportunities for students' growth in understanding relative to where they started. To cultivate a positive learning environment and ensure students understand how they will be assessed, these ideas should be explicitly addressed with students. This is especially the case with tiered activities where the perception is prevalent that some tiers are "harder" or require "more work" than others. We recommend providing students with an outline of what process skills and concepts will be assessed for each tier at the beginning of the activity and asking them why they think there are differences in what is being assessed (Figure 5). The teacher should lead students to the idea that students in the class currently have varied levels of expertise in designing and conducting experiments and that the assessment of each tier reflects these differences, but that the overall amount of thinking individual students will need to do is the same if the teacher appropriately placed them in tiers.

Modifications

Several modifications to the activity described above are possible. For example, teachers could create a fourth tier, open inquiry, in which students develop their own question to explore the topic of density and then design an experiment to answer this question. Students in this tier understand how to come up

FIGURE 5 Outline for evaluating tiered inquiry activity

Tier 1

1. Data are accurately inputted into table with units.
2. Data are accurately graphed with Logger Pro software.
3. Density is calculated from data.
4. Two approaches to calculating density are analyzed.
5. Percentage error is calculated.
6. Conclusion questions are answered.
    a. Conceptual: Answer to research question is supported with evidence and includes an explanation of density.
    b. Procedural: Discussion includes what could be changed to decrease error and alternative approaches.
    c. Reflection/metacognitive: There is discussion of what was learned.
    d. Nature of science: There is discussion of what differences in students' approaches tells them about how science is done.

Tier 2

1. Data table has been developed and data accurately inputted.

2–6. Repeated from Tier 2.

Tier 3

1. Procedure to answer research question has been developed.
2. Data table or graph has been developed and data accurately inputted.
3. Density is calculated from data.
4. Two approaches to calculating density are analyzed.
5. Percentage error is calculated.
6. Conclusion questions are answered.
    a. Conceptual: Answer to research question is supported with evidence and includes an explanation of density.
    b. Procedural: Discussion includes what could be changed to decrease error and alternative approaches.
    c. Reflection/metacognitive: There is discussion of what was learned.
    d. Nature of science: There is discussion of what differences in students' approaches tells them about how science is done.

with a science research question and design an experiment; they would be working at the highest level of abstractness and with the least amount of support from the teacher. Alternatively, while it does not align directly with an inquiry level, teachers could also create a less guided tier in which students are given the question and directions for graphing and analysis but not a procedure. This tier would be useful for those students who understand how to collect data but still struggle with how to analyze and graph data after collection.

Another possible modification to this activity is to debrief one aspect of the nature of science as part of the activity. Students will most likely be aware of how their peers approach the activity differently. Since some students in the class write their own procedure, it is appropriate to discuss how scientists use many methods, not just *one* scientific method, to develop scientific knowledge. This is a key tenet of the nature of science and one that most students have alternative conceptions about. Debriefing conclusion question 6 (Figure 2) can provide an opportunity to emphasize this particular tenet (Bell 2008).

Finally, while we used Logger Pro software to create the graphs, the directions could easily be modified to accommodate equivalent software (e.g., Excel) that is available at your school. Alternatively, students could create the graphs and determine the slope of the lines by hand.

Conclusion

The tiered activity described above differentiates the process through which students complete the activity by varying the inquiry level. However, the need to develop multiple activities focused on achieving the same learning goals can often be challenging for teachers to plan and implement. By approaching tiered activities as described in the example above, teachers can easily modify an investigation so that all students are engaged in tasks at the appropriate challenge level. This allows students to work at their own readiness level and teachers to provide the support needed to move students toward open-inquiry investigations. It also allows the teacher to prepare for one investigation, rather than three or four, while still providing different degrees of complexity and abstractness for students. Therefore, a tiered inquiry activity can be an effective way to differentiate instruction based on variations in students' scientific-practices readiness in the science classroom. ■

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