The Use of Dialogue to Build Scientific Literacy in the Laboratory Setting

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Abstract: Students who are scientifically literate demonstrate the ability to use verbal descriptions, pictorial representations, the language of mathematics, and technological applications to build conceptual models of natural phenomena that are useful for describing observations and making predictions based on observations. The laboratory setting is ideal for the use of classroom dialogue that emphasizes invitational questioning to identify student preconceptions, gently expose misconceptions, and help students extend their understanding in ways that enable them to reconceptualize their prior knowledge. A framework for designing laboratory experiences to emphasize invitational questioning and conversational interaction to integrate as many of the four domains of scientific literacy as possible, is proposed in this manuscript.

Introduction

A primary challenge I have faced in my 28 years of classroom experience has been initiating and maintaining of effective classroom dialogue. Prior to entering teaching, I had been a cardiopulmonary technologist, working for several years in a teaching hospital. As part of my professional responsibilities in critical care, I accompanied medical residents, interns, and students, as they made bedside rounds with the chief physician of critical care services. The day-to-day training relied on Socratic Dialogue, ideally a methodology in which questions are asked to ascertain current knowledge with follow up questions directed toward the expansion of knowledge (Stoddard & O'Dell, 2016). Frequently, with the chief of service doing the questioning, the sessions were uncomfortable to witness, with the tone of questioning highly confrontational and a failure to provide adequate answers eliciting sarcastic and humiliating retorts from the questioner.

In recent years, the medical education community has begun to look with disfavor on this highly confrontational questioning style. The goal of Socratic questioning should be to identify prior knowledge and awaken connections with new knowledge, an invitational paradigm, rather than emphasizing hierarchal judgment and confrontation (Oh & Reamy, 2014). A medical resident's literacy would be supported by verbal descriptions integrating quantitative data, pictorial representations and the use of technological applications in assessing the status of the patient in question. The persistence of the use of Socratic Method in the training of medical residents lies in its utility for stimulating critical thinking while exposing prior learning and misconceptions (Huang, 2005). Yet the Socratic method need not be confrontational; at its best effective Socratic dialogue is instead invitational, inviting conversation rather than confronting the subject of questioning.

A Framework for Scientific Literacy

The medical literacy sought through the use of Socratic dialogue is analogous to the scientific literacy we seek in the classroom. An operational definition of scientific literacy incorporates four domains: natural language (verbal descriptions), mathematical descriptions (equation based), pictorial representations such as particle or motion diagrams, and technological applications using spreadsheet-based graphical representations and data collection software and hardware (Lemke, 2004). Another way to describe these four domains is, (1) practical knowledge from observations, (2) qualitative physical models utilizing diagrams, (3) concrete mathematical models incorporating measurements and graphing, and (4) written symbol manipulations integrating equations and calculations (Clement, 1978). The framework of common laboratory experiences can provide a template for building scientific literacy integrating all four of these literacy domains, as described by Lemke (2004) and Clement (1978).

Traditional laboratory activities often follow a 'cookbook format,' offering explicit instructions that students are expected to follow verbatim; this structure can inhibit opportunities to stimulate thinking in students due to the passivity of students working within this model (Germann, Halkins, & Auls, 1996). By applying a template developed from the literacy domains described by Lemke (2004) and Clement (1978) teachers of all experience levels can design laboratory experiences that integrate invitational dialogue to help build student's scientific literacy. It is understood, especially at lower grade levels, many laboratory activities are qualitative in nature rather than quantitative, so not all laboratory activities will incorporate all four domains. The goal should be to incorporate as many domains as possible, with invitational questioning and dialogue as the bridge integrating them, to achieve the goal of students actively "doing" science.

Domain 1: Natural Language Verbal Descriptions

The natural language domain is over-arching; assessing student literacy in the other three domains will always incorporate their observations, analysis and predictions as expressed in their natural language. Written assessments are generally dominant in the classroom setting, and are often a necessity because of the demand that students document their progress, but they are limited in their usefulness because of lack of opportunities for clarification and correction in real time. The intentional use of invitational dialogue allows for diagnosis of current knowledge levels, conceptual understanding, and possible misconceptions because of the dynamic nature of dialogue.

Typically, laboratory handouts in pre-laboratory sections introduce students to scientific vocabulary that describes the experimental variables, safety procedures, and calculations that the student must use to evaluate laboratory data. While informative, these types of handouts lack the capacity to confront student misconceptions based on prior knowledge and experience, misconceptions that frequently hinder student acquisition of conceptual understanding necessary to construct correct scientific models of natural phenomena (National Research Council, 1997).

For example, a common misconception that students bring into the classroom is that heat and temperature are synonymous. Careful questioning can quickly assess whether this is an issue. Yet simply asking a student to define temperature and heat, or to state the difference between them, is confrontational and limiting; the student will usually respond with a formal definition using scientific language, understanding that their answer is subject to the teacher's evaluation and judgment. An invitational way of asking this question is to make it open-ended by asking something like "what do we know about temperature and heat?" Though this may seem like a very subtle difference, asking it in this way deescalates the sense of judgment that questioning often stimulates. The goal is to provide a structure in which students are at liberty to use their natural language rather than relying on more formal scientific language. If the answers that students give reflect the misconception that temperature and heat are the same, a simple set of questions can guide students to differentiate between them. For example, you can ask students what a thimble full of boiling water and a bucket full of boiling water have in common. They will answer that both are 100oC water, the temperature is the same. Agreeing with them that the temperature is the same, then you can ask if the thimble and bucket contain the same amount of heat. In my experience, there is usually a pause before students answer because this question directly confronts the misconception. If there is a pause, I ask them which would do more damage if the contents were spilled on their arm; at this point all students will grasp that heat content is dependent on the amount of the substance, not just its temperature, since a bucket full of boiling water would do much more damage than a thimble full of boiling water. Dialogue such as this is non-judgmental and safe for students, and it provides an opportunity to extend student understanding in an atmosphere that builds trust. It is critical in the questioning process that the teacher does not devalue or denigrate students' initial responses, because this can cause students to become fearful and unwilling to engage. Invitational questioning facilitates a reconceptualization process, a clarification, and perhaps replacement of prior knowledge and conceptual understanding (Posner, Strike, Hewson, & Gertzog, 1982).

Domain 2: Pictorial Representations and Diagrams

The use of whiteboards in the laboratory setting for the pictorial representation of student conceptual understanding is both practical and generally a positive experience for students. Pictorial representations externally manifest internal understanding (Johnson-Laird, 1980). It is critical to the process that the instructor engages students with questions from both domains 1 and 2 while the whiteboard preparation takes place. If there is something very obviously wrong with their predictions or diagrams that could lead to embarrassment during the pre or post-laboratory presentations, assistance can be offered to the students in a more private setting. Effective dialogue is based in trust. Generally, I have found it most effective if all of the whiteboards are displayed simultaneously with the instructor choosing two or more of the whiteboards for discussion. The first task for students is to look at all of the whiteboards, note similarities and differences, and discuss these within their groups.

Invitational dialogue emphasizes open-ended questions, such as a simple "tell us about your diagram or picture." Again, the goal is to facilitate student expression in their initial response, which enables the teacher to extend student understanding through follow-up questions. A key here is the use of natural language; if students respond in what I call science vernacular, I ask them to explain again in words that a non-scientist would understand. This is important because often our students have internalized theoretical definitions using proper scientific terminology but lack the conceptual understanding to express an operational definition, a definition that is based on our observational senses and that demonstrates understanding that extends beyond the immediate situation.

Pictorial diagrams are useful not only in helping students learn science, but also in helping them produce knowledge (Evagorou, Erduran, & Mantyla, 2015). An example of pictorial representation done on a whiteboard from a lab that addresses the effect of changing temperature on the pressure of a gas is shown in Figure 1:

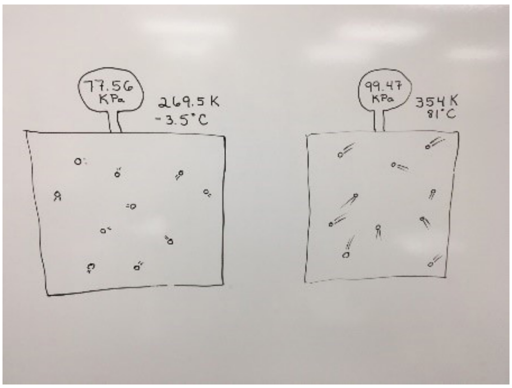

Figure 1. Pictorial representation of pressure (kPa) of gases at different temperatures (K).

One of the strengths of dialogue centering on pictorial representations and diagrams is that such discussions are not limited to labs that are quantitative in nature, but are also useful in qualitative or descriptive labs as well.

Domain 3: Technology Applications

Effective use of technological applications enables students to engage in knowledge construction and to develop sophisticated problem solving skills (Trowbridge, Bybee & Powell, 2008). For example, spreadsheet programs allow students to quickly generate graphical representations of their data as well as to construct mathematically fitted curves and equations of best-fit lines. In Figure 2, Microsoft Excel was used to generate a graph for the lab described earlier which explored the relationship between pressure and changing temperature.

Student-generated graphs can be displayed using an overhead projector and discussions should begin with invitational, open-ended questions such as "explain what your graph represents." The depth of the answer to this question will dictate the direction of the instructor's questioning, with the goal of extending and clarifying knowledge. A close examination of the example graph shows the equation of the best-fit line present, a representation that combines the graphical and mathematical domains. In this way the four domains crucial to scientific literacy often cross over and are rarely exclusive of the others, especially when quantitative data is represented. The instructor can also open up questions to other students, which can help reveal the depth of conceptual understanding of the students asking questions. Again, care has to be taken here that the atmosphere of safety and trust is not compromised, and that students do not feel judged or criticized.

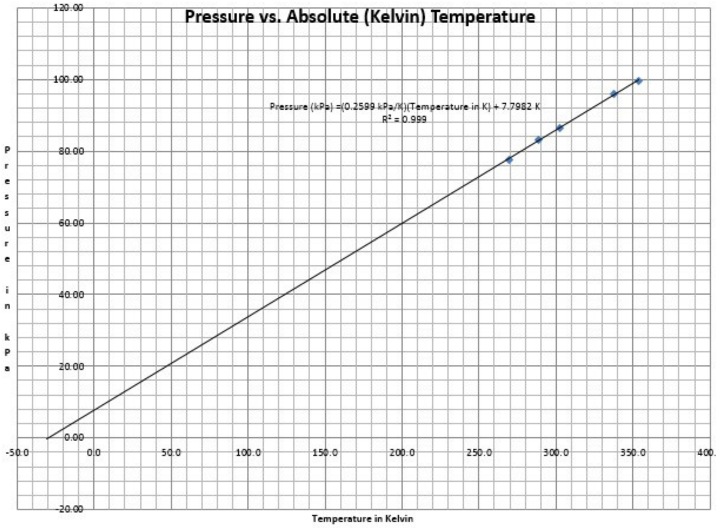

Figure 2: Graph of pressure and absolute temperature relationship from Gay-Lussac's law laboratory activity.

Domain 4: Mathematical Descriptions (Equations)

Students in advanced science classes such as physics are often adept at using equations to solve problems. For instance, given the quantities of mass and acceleration, students can use the equation Force = mass X acceleration (F = ma) to calculate the amount of force that must be applied to an object to cause acceleration. However, it is much more challenging for students if you ask them to express what F = ma means in words. Students at this level are often more comfortable with manipulating numbers by rearranging equations than expressing their conceptual understanding in words. An astute student will recognize in the equation that acceleration is directly proportional to the force applied if the mass is kept constant and inversely proportional to the mass of the object if the force is kept constant. Invitational dialogue can help students develop their natural language in expressing mathematical relationships, and can help them develop such understandings.

Students typically recognize the equation of a straight line applied to a straight line curve on a graph quickly (as seen in Figure 1). Often, students will default to describing it by offering the equation y = mx + b. Invitational questioning can help students extend and clarify their knowledge by simply asking them to use their natural language to replace the symbols in the equation. In the equation on the graph in Figure 1, y represents the pressure in kPa, m represents the slope of the line in kPa per Kelvin, x represents the temperature in Kelvin and b represents the pressure when the temperature is 0 Kelvin. This language skill can be reinforced by asking students to make predictions about relationships and to describe the behavior without numbers, given the equation or a picture of the graphical curve. For instance, if the curve of the graph is not linear, asking students to explain how they could linearize the graph will give great insight into student's mathematical literacy. A graphical curve representing an inverse relationship such as pressure vs. volume of a gas at constant temperature, can be linearized by graphing the pressure vs. the inverse of the volume ($P \propto 1/V$). The slope of this curve represents a product equal to a constant, ($PV = k$), rather than a ratio equal to a constant such as the relationship of pressure and temperature, ($P/T = k$). The relationship of distance traveled vs. time while the object increases in velocity shows a graphical curve that is a top-opening parabola, rather than a straight line. The graph can be linearized by graphing the distance vs. the square of the time ($d \propto t2$). The ratio represented by the equation that represents this relationship, $d/t2 = k$, the constant k represents the acceleration of the system. Asking students to relate the equations that describe the system to the slope revealed in a linear or linearized graphical representation requires the integration of the two most difficult domains of scientific literacy while expressing this understanding in a third domain, that of natural language. Requiring the use of motion or particle diagrams in their explanations links all four domains. Students find this challenging at first, similar to learning a foreign language, but their ability to make coherent predictions demonstrates understanding from a performance perspective (Perkins, 1993). Patient, invitational dialogue is the key to building the linguistic skills necessary to express correct conceptual understanding, as well as helping students further and correct their conceptual understandings.

Conclusion

Linking types of representations of scientific data can result in improved learning of science content (Basu, Biswas, & Kinnebrew, 2016). Invitational, rather than confrontational, questioning techniques that address the four domains of knowledge as addressed by Lemke (2004) and Clement (1978) can provide a concrete pedagogical foundation for increasing scientific literacy in the classroom that is both observable and measurable, and can help students engage in this linking. Through such questioning teachers can easily assess student understanding, by providing students with data from one or two of the domains described and asking them what the appropriate remaining domains would look like. Teachers planning laboratory or recitation activities can refer to the four domains as a way to self-assess their activity's ability to build scientific literacy. If it is impractical for all four domains to be addressed in a single lesson, teachers can still work to maximize the number of domains incorporated in the activity, and can consider the kinds of questions will serve as bridges between the domains. Beyond the ability to link domains through such questioning, invitational questioning and the conversations that ensue also affirm the value of the humanity of our students. This is of inestimable worth.

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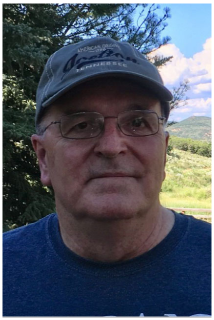

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