Using Yeast Fermentation as a Context for Meaningful Learning of Procedural Understanding

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INQUIRY & INVESTIGATION

ABSTRACT

Students need procedural understanding—that is, knowledge of the procedures that scientists use to establish scientific evidence (also known as “concepts of evidence”), to successfully perform scientific investigations, and to evaluate public and scientific claims. However, concepts of evidence are seldom explicitly targeted in routine practical activities in secondary school science classrooms. We describe how a commonly used practical activity, yeast fermentation, can be modified to provide a meaningful context for developing students’ understanding of concepts of evidence associated with measurement, as well as more difficult-to-learn scientific ideas, such as rates of reaction. The modified practical activities give students opportunities to exercise their creativity in assembling setups; brainstorm solutions to design problems in teams; reflect on their decisions related to concepts of evidence associated with measurement when designing their setups; compare the validity and reliability of data produced using different setups; and develop their understanding of difficult-to-learn scientific ideas.

Key Words: procedural understanding, concepts of evidence, yeast fermentation.

Introduction

Scientific literacy is a valuable goal of science education (DeBoer, 2000; Organisation for Economic Co-operation and Development, 2019). Douglas Roberts (2007) identified two visions of scientific literacy: Vision I and Vision II. Vision I “looks inward” at science and is mainly concerned with development of the understanding of scientific content, skills, or competence that are considered important by the scientific discipline. Vision II “looks outward” to the role of science in human affairs and relates to students’ functional engagement with scientific ideas in the context of social issues related to science. Central to both visions of scientific literacy is an understanding of scientific evidence (Roberts & Gott, 2002). Such an understanding is crucial to deciding whether scientists’ claims, or public claims, about science are warranted by valid and reliable evidence.

Understanding evidence involves understanding the validity and reliability of data, which are in turn determined by the methods and procedures used to derive the data. Research has revealed that a body of knowledge of data collection and interpretation needs to be understood and applied when handling scientific evidence (Gott & Duggan, 1996). For example, scientists often repeat measurements to reduce experimental error when collecting data. They focus on specific variables and seek to identify their patterns when interpreting data. Understanding of the procedures that scientists use to establish scientific knowledge, or “concepts of evidence,” is referred to as “procedural understanding” (Roberts, 2001; Gott & Roberts, 2008) or “procedural knowledge” (Organisation for Economic Co-operation and Development, 2016). By using the label “procedural understanding,” researchers highlight that there exists a distinct knowledge base underlying what scientifically literate people use to understand scientific evidence. The application of these ideas in scientific investigations constitutes the “thinking behind the doing” (Roberts et al., 2010). For example, Biffler et al. (2001) highlight the importance of procedural understanding to the success of investigative practical work, because not only an understanding of scientific ideas but also procedural understanding is required to inform decision making in various phases of scientific investigation, including planning, handling data, and drawing conclusions from data. There is some evidence that interventions involving the explicit teaching of procedural understanding can improve students’ performance in open-ended investigations (Glaesser et al., 2009).
In a series of articles, Ros Roberts and her colleagues argue that concepts of evidence should be considered as a cognitive outcome and are as much an aspect of subject matter as other science ideas (Roberts & Gott, 1999, Roberts, 2001, Roberts & Reading, 2015). The researchers note that many students will not develop a nuanced understanding of concepts of evidence if these ideas are not explicitly targeted in instruction. This may be done through practical or nonpractical activities. They further point out that in most practical activities used, experimental conditions are often optimized such that the practical work will generate the expected results to illustrate certain scientific ideas. This kind of practical work provides little room to develop students’ understanding of concepts of evidence. The researchers hence suggest using contexts in which students are unaware of the “right answer,” and which focus their attention instead on the quality of the evidence and thus on concepts of evidence (Roberts & Reading, 2015). We agree that routinized, recipe-like practical work rarely provides a meaningful context for students’ learning of concepts of evidence. However, we believe that teachers may regard new practical work that is only tangentially related to scientific ideas in the curriculum as merely an add-on to an already crowded curriculum, and thus as a burden. Moreover, we believe that merely doing unfamiliar practical work activities does not necessarily result in meaningful learning and that teachers need to support students in constructing links between what they do in the practical work and the ideas intended (Abrahams & Millar, 2008). We contend that when designing scientific investigations, students need to be given structured opportunities for reflection on their decisions related to concepts of evidence.

In this article, we illustrate how a practical activity commonly conducted in Hong Kong secondary school biology classrooms can be modified to provide a meaningful context for developing biology students’ understanding of concepts of evidence and more difficult-to-learn scientific ideas. Specifically, we show how a practical activity related to yeast fermentation can be used to develop students’ understanding of concepts of evidence associated with measurement (Table 1). Such an understanding is crucial for obtaining precise, reliable, and valid data for interpretation (Buffler et al., 2001; Gott & Roberts, 2008) and has so far received comparatively less attention than concepts of evidence, such as understanding the ideas related to control of variables (Zimmerman, 2007). For a list of concepts of evidence proposed by Gott and Duggan (1996), see Appendix S1 (in the Supplemental Material available with the online version of this article). A fuller list is available online (Gott et al., 2019). The key scientific idea on which we focus is reaction rate, an idea that is relevant to various topics in biology (e.g., enzymes, photosynthesis, respiration, and transpiration) and is difficult to learn (Cakmakci et al., 2006).

Organism of Study & Its Relevance for the Curriculum

Baker’s yeast (Saccharomyces cerevisiae) is a versatile and useful organism in science classrooms (Marshall, 2019). In Hong Kong, high school biology students (grades 10–13) are required to understand the metabolic process of yeast fermentation (Curriculum Development Council, 2007). In textbooks commonly used in Hong Kong, teachers are advised to use setups with optimized conditions in teacher-led demonstrations or to engage students in designing investigations related to yeast fermentation (Yung et al., 2014). The former approach illustrates the scientific ideas, whereas the latter emphasizes the variables (CoE 1 in Appendix S1). In this proposed practical work activity, we use 15% yeast extract (15 g dry yeast in 100 mL boiled distilled water) and sugar (0.5 M sucrose solution), but we focus on teaching and learning the concepts of evidence associated with measurement (Table 1).

Proposed Practical Activity for Teaching Concepts of Evidence

Table 2 shows the suggested lesson sequence. The lesson plan has seven stages, and we suggest that teachers make use of a double lesson (40 minutes per lesson) for stages 1 to 4 and a single lesson (40 minutes) for stages 5 to 7. Below, we describe the procedures in each stage and the rationales behind the design.
Table 2. Suggested lesson plan.

| Lesson | Sequence | Duration (minutes) |
|--------|----------|--------------------|
| 1, 2   | **Stage 1: Activation of students’ prerequisite knowledge** | 10 |
|        | • The teacher shows a picture related to bread making and leads an interactive discussion to activate the basic knowledge required to understand the design challenge (i.e., knowledge of yeast fermentation). | |
| 3      | **Stage 2: Discussion on the possible measurement parameters** | 5 |
|        | • The teacher guides the students to think of appropriate parameters and measures for the rate of yeast fermentation (Task A). | |
| 3      | **Stage 3: Design challenge** | 5 |
|        | • The students visit the materials and apparatus station to gain a sense of the instruments and chemicals available for the design challenge activity. | |
| 3      | • The students are allowed to ask questions about unfamiliar aspects of the apparatus (e.g., diazine green). | 10 |
| 3      | • The students individually draw the possible setups (Task B). | 10 |
| 3      | • In groups of three or four, the students discuss the possible setups and their biological principles (Task C). | 30 |
| 3      | • The students work in groups to assemble the setups. | |
| 3      | **Stage 4: Reflective discussion on the design challenge** | 10 |
|        | • The teacher leads an interactive discussion of the challenges involved in assembling the setups and the scientific ideas and concepts of evidence associated with the measurement process. | |
| 3      | **Stage 5: Selection of “best” setup** | 5 |
|        | • The students are asked to select the best of the setups they have assembled. They are also required to justify their choices (Task D). | |
| 3      | • Each group of students is asked to display its best setup at a laboratory station. | |
| 3      | **Stage 6: Gallery walk of possible setups** | 25 |
|        | • The students are regrouped such that each group comprises one member of each of the previous teams. | |
| 3      | • The new teams visit each of the laboratory stations. At each station, the member who assembled the setup on display is responsible for explaining the setup and explaining why it was chosen as the best by his or her previous group members. The new team is also prompted to select one setup that will produce the most valid data (Task E). | |
| 3      | **Stage 7: Reflective discussion on criteria for “best” setup** | 10 |
|        | • The teacher leads a discussion of the criteria used to appraise the setup and a discussion of the concepts of evidence associated with measurement. | |

**Stage 1: Activation of Students’ Prerequisite Knowledge**

The students are asked to describe the chemical reaction that occurs during yeast fermentation and provide the word equation that represents the reaction. This stage serves to activate students’ prior knowledge related to the practical work.

**Stage 2: Discussion of the Possible Measurement Parameters**

The students are then invited to engage in an interactive discussion focusing on the possible parameters and measures of the rate of yeast fermentation. This discussion focuses the students’ attention on the advantages and limitations of using each of the possible
parameters and measures of the rate of yeast fermentation (for a list that can prepare teachers for the discussion, see Table 3). To encourage the students to consider concepts of evidence such as relative scale and choice of instruments, the teacher can also introduce an instrument used to measure changes in ethanol concentration (e.g., a wine hydrometer) and note its limitations (e.g., producing satisfactory readings only for sugar solutions with concentrations >0.25 M; Freeland, 1973). This stage focuses students’ attention on concepts of evidence associated with measurement.

Stage 3: Design Challenge

In this stage, the students are given opportunities to design their own setups using yeast extract along with a wide variety of instruments and chemicals (for the materials made available to students, see Figure 1). The students are challenged to assemble as many setups as possible to accurately and reliably measure the rate of fermentation of yeast. The list of materials comprises apparatuses that have similar functions but differ in size. A list of reagents and their functions can be found in Appendix S2. For a variety of setups with different working principles that can be assembled using the given materials, see Appendix S3.

Before engaging in this activity, the students have a chance to see the range of instruments and chemicals available. A teacher-led discussion follows, allowing the students to ask questions about the functions of unfamiliar instruments (e.g., Hoffman clip) and chemicals (e.g., diazine green). They are then given several minutes to sketch the possible setups individually (Appendix S4). Subsequently, they are divided into groups of four to discuss and share their ideas for possible setups and their working principles. Next, they are given time to assemble the real setups. Each group is tasked with explaining the working principles of their chosen setups (Appendix S5). They can make use of the yeast extract and sucrose solution (supplied in a 500 mL beaker) for trial testing of their assembled setups. The students are given apparatuses with different size ranges, which allows them to design setups with different sizes and consider issues related to relative scale, accuracy, and repeatability. For example, the students may need to use a larger volume of yeast extract if they wish to produce a measurable change in the mass of the reaction mixture. This stage also enables the students to exercise their creativity and use their problem-solving skills to troubleshoot problems they encounter during the design and assembly of the setups.

Stage 4: Reflective Discussion on the Design Challenge

After each group has assembled its chosen setups, the teacher initiates a reflective discussion of the challenges encountered so far (for a list of possible guiding questions, see Appendix S6). The discussion may start with fundamental questions such as how to make sure that the setup is airtight, ensuring an anaerobic environment such that the yeast will carry out fermentation, and how to make sure that the carbon dioxide produced can be translated into measurable changes (e.g., changes in volume, gas pressure, or acidity). Another focus of the discussion is relevant scientific ideas. These may include how the rate of fermentation can be measured using the same setup and scientific ideas that were unclear to the students when developing the setups. Issues related to concepts of evidence associated with measurement, such as the size of the setups, the optimal volume of yeast-sugar extract, and the inclusion of replicates, can also be targeted. This stage provides structured opportunities for teachers to discuss students’ scientific ideas and issues related to concepts of evidence. Although we recommend that teachers focus on concepts of evidence associated with measurement, teachers may also choose to discuss with students concepts of evidence related to design (e.g., Should temperature be held constant? Why?).

Stage 5: Selection of “Best” Setup

After the students have designed their setups, they are asked to engage in group discussion to select the “best” of the setups they have assembled. They are explicitly prompted to identify the criteria used to choose the optimal setup (Appendix S7). Next, the groups display their chosen setups at laboratory stations. This stage provides a chance for the students to choose and display the “best” setups; they have opportunities to determine why certain setups are better than others by articulating the criteria used in their judgment and evaluation.

Stage 6: Gallery Walk of Possible Setups

The class is then regrouped such that each group contains one member from each of the original groups (a method of regrouping similar to the expert jigsaw strategy; Kruse, 2009). The new teams then rotate to the various stations. The student who assembled the setup displayed at a given station explains the biological principles of the setup and why they considered this setup the best (Appendix S8).
Figure 1. Materials available to students.
Stage 7: Reflective Discussion on Criteria for “Best” Setup

After the rotation activity, the teacher leads a discussion of each team’s reasons for regarding its chosen setup as optimal. Their choices may be related to the problems associated with some of the setups, such as production of foam, probability of leakage, price, cumbersomeness of assembly (Reinking et al., 1994), or the validity and reliability of the data that can be generated. The teacher can also explicitly prompt discussion of concepts of evidence associated with measurement (e.g., accuracy, repeatability, choice of equipment) and the setup that can generate the most valid data. For example, the teacher may pose questions about the advantages of using Grammer’s (2012) setup. This stage allows teachers to help students develop an understanding of concepts of evidence associated with measurement, such as relative scale, range and interval, choice of instruments, repeatability, and accuracy.

○ Conclusion

In summary, we have illustrated how we modified a practical activity commonly used in Hong Kong secondary school biology classrooms to develop students’ understanding of concepts of evidence associated with measurement and other difficult-to-learn scientific concepts (e.g., rates of reaction). The activities give students opportunities to work in teams to assemble setups, try out ways of refining their decisions on instruments and relative scale, and solve problems on their own. Overall, the activities allow for multiple answers and promote students’ creativity and problem-solving skills. Although we illustrate our modifications in the context of a specific practical topic (i.e., yeast fermentation), we believe that some of the general strategies (e.g., design challenge, reflective discussion of issues related to concepts of evidence) can be applied to other practical work contexts. We hope that our example will inspire teachers to embed the teaching of concepts of evidence in their own contexts.

○ Supplemental Material

The following appendices are available with the online version of this article:

- Appendix S1: Concepts of Evidence
- Appendix S2: Reagents Supplied and Their Functions
- Appendix S3: List of Possible Setups
- Appendix S4: Individual Worksheet
- Appendix S5: Group Worksheet 1
- Appendix S6: Possible Grading Questions
- Appendix S7: Group Worksheet 2
- Appendix S8: Group Worksheet 3

References

Abrahams, I. & Millar, R. (2008). Does practical work really work? A study of the effectiveness of practical work as a teaching and learning method in school science. International Journal of Science Education, 30(14), 1915–1969.

Buffer, A., Allie, S. & Lubben, F. (2001). The development of first year physics students’ ideas about measurement in terms of point and set paradigms. International Journal of Science Education, 23(11), 1137–1156.

Cakmakci, G., Leach, J. & Donnelly, J. (2006). Students’ ideas about reaction rate and its relationship with concentration or pressure. International Journal of Science Education, 28(15), 1795–1815.

Chan, K.K.H. (2016). A simple micro-scale setup for investigating yeast respiration in high school biology classrooms. American Biology Teacher, 78(8), 669–675.

Collins, L.T. & Bell, R.P. (2004). How to generate understanding of the scientific process in introductory biology. American Biology Teacher, 66, 51–53.

Curriculum Development Council (2007). Science Education Key Learning Area: Biology Curriculum and Assessment Guide (Secondary 4–5). Hong Kong: Government Printer.

DeBoer, G.E. (2000). Scientific literacy: another look at its historical and contemporary meanings and its relationship to science education reform. Journal of Research in Science Teaching, 37(6), 582–601.

Freeland, P.W. (1973). Some practical aspects of sugar fermentation by baker’s yeast (Saccharomyces cerevisiae). Journal of Biological Education, 7(5), 14–22.

Glaesser, J., Gott, R., Roberts, R. & Cooper, B. (2009). Underlying success in open-ended investigations in science: using qualitative comparative analysis to identify necessary and sufficient conditions. Research in Science & Technological Education, 27(1), 5–30.

Gott, R. & Duggan, S. (1996). Practical work: its role in the understanding of evidence in science. International Journal of Science Education, 18(7), 791–806.

Gott, R., Duggan, S., Roberts, R. & Hussain, A. (2019). Research into understanding scientific evidence. http://community.dur.ac.uk/rosalyn.roberts/Evidence/CofEv_Gott%20set%20of%20tools.pdf.

Gott, R. & Roberts, R. (2008). Concepts of evidence and their role in open-ended practical investigations and scientific literacy: background to published papers. Durham, UK: School of Education, Durham University.

Grammer, R.T. (2012). Quantitation & case-study-driven inquiry to enhance understanding scientific evidence. http://community.dur.ac.uk/rosalyn.roberts/Evidence/CofEv_Gott%20set%20of%20tools.pdf.

Knable, M.T. & Misquith, G. (2006). Assessing inquiry process skills in the lab using a fast, simple, inexpensive fermentation model. American Biology Teacher, 68(4), 25–28.

Kruse, D. (2009). Thinking Strategies for the Inquiry Classroom. Carlton South, Australia: Curriculum Press.

Marshall, P.A. (2019). Utilizing Saccharomyces in the classroom: a versatile organism for teaching and learning. Journal of Biological Education, 53(2), 179–190.

Organisation for Economic Co-operation and Development (2016). PISA 2015 Assessment and Analytical Framework: Science, Reading, Mathematics and Financial Literacy. Paris: PISA, OECD Publishing.

Organisation for Economic Co-operation and Development (2019). PISA for Development Assessment and Analytical Framework: Reading, Mathematics and Science. Paris: PISA, OECD Publishing.
Reinking, L.R., Reinking, J.L. & Miller, K. (1994). Fermentation, respiration & enzyme specificity: a simple device & key experiments with yeast. American Biology Teacher, 56(3), 164–168.

Roberts, D.A. (2007). Scientific literacy/science literacy. In S.K. Abell & N. Lederman (Eds.), Handbook of Research on Science Education (pp. 729–780). Mahwah, NJ: Lawrence Erlbaum Associates.

Roberts, R. (2001). Procedural understanding in biology: the ‘thinking behind the doing’. Journal of Biological Education, 35(3), 113–117.

Roberts, R. & Gott, R. (1999). Procedural understanding: its place in the biology curriculum. School Science Review, 81(294), 19–25.

Roberts, R. & Gott, R. (2002). Collecting and using evidence. In D. Sang & V. Wood-Robinson (Eds.), Teaching Secondary Scientific Enquiry. London: ASE/John Murray.

Roberts, R., Gott, R. & Glaesser, J. (2010). Students’ approaches to open-ended science investigation: the importance of substantive and procedural understanding. Research Papers in Education, 25(4), 377–407.

Roberts, R. & Reading, C. (2015). The practical work challenge: incorporating the explicit teaching of evidence in subject content. School Science Review, 96(357), 31–39.

Weinberg, R.B. (2018). Measuring yeast fermentation kinetics with a homemade water displacement volumetric gasometer. Journal of Chemical Education, 95(5), 828–832.

Yung, H.W., Ho, K.M., Tam, K.H. & Tong, L.P. (2014). New Senior Secondary Mastering Biology, Book 3, Teacher’s Edition, 2nd ed. Hong Kong: Oxford University Press (China) Limited.

Yurkiewicz, W.J., Ostrovsky, D.S. & Knickerbocker, C.B. (1989). A simple demonstration of fermentation. American Biology Teacher, 51(3), 168–169.

Zimmerman, C. (2007). The development of scientific thinking skills in elementary and middle school. Developmental Review, 27(2), 172–223.

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