FEATURE ARTICLE

Using Natural Selection Concept Inventories in College Biology Classrooms to Improve Teaching and Learning

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Abstract

The purpose of this study was to investigate how assessment instruments could be used in the college biology classroom for purposes other than researching instructional strategies (as they have been used in the past). Through participatory action research, a science educator and a biology faculty member examined how the CINS (Concept Inventory of Natural Selection) could be incorporated into the biology faculty member's classroom instruction. This paper shows that biology faculty members can use assessment instruments to build in-class activities and labs, to formatively assess student knowledge, and to confront student misconceptions. Several recommendations for incorporating assessment instruments in biology instruction and assessment are provided.

Key Words: *assessment instrument; biology; college; teaching and learning; natural selection.*

○ Introduction

As science faculty members, we are encouraged to use assessment as a support *for* learning, rather than strictly an evaluation *of* learning (Black & Wiliam, 1998). That is, assessment should be a tool to help improve teaching and learning. However, designing assessments was likely not part of our preparation as faculty, and we may find that few available professional development opportunities and resources are focused on helping faculty develop valid and reliable assessments to collect and use assessment data to inform our instruction. Through a participatory action research (PAR) collaboration, we explored how faculty can incorporate high-quality assessment instruments, such as concept inventories and diagnostic tests, in the college science classroom in ways that support teaching and learning, as opposed to simply evaluating and grading students. In this paper, we will share how we were able to incorporate existing assessment instruments in a college science classroom to support teaching and learning.

> *Constructing high-quality assessments is a difficult and time-consuming process.*

○ Assessment Instruments

Constructing high-quality assessments is a difficult and time-consuming process, and faculty-made tests have often been criticized for promoting memorization of factual knowledge and for not accurately reflecting student understanding (Tobias & Raphael, 1997). Rather than constructing assessments from scratch, faculty can draw on a number of already-developed assessment instruments. Concept inventories and diagnostic tests are assessment instruments that contain multiple-choice items that assess student understanding of a particular concept or topic. These assessment instruments are research-based and, ideally, are subject to a rigorous process to calculate validity and reliability measures. These measures allow researchers to be confident in the instrument's ability to accurately reflect student understanding of a concept (Treagust, 1995).

In the sciences, several assessment instruments have been developed and validated. For example, instruments have been used to investigate student understanding of natural selection (e.g., Anderson et al., 2002), basic molecular biology (e.g., Klymkowsky & Garvin-Doxas, 2008), force and motion (e.g., Hestenes et al., 1992), genetics (e.g., Bowling et al., 2008), osmosis and diffusion (e.g., Odom & Barrow, 1995), light and spectroscopy (e.g., Prather et al., 2009), astronomy (e.g., Slater & Slater, 2008), chemistry (e.g., Landis et al., 2000), and the geosciences (e.g., Libarkin & Anderson, 2006), just to name a few. Other resources are available that provide individual assessment items, such as the AAAS science assessment item bank (AAAS, 2014). Several studies have shown that assessment instruments can be used to evaluate the effectiveness of

The American Biology Teacher, Vol. 79, No 2, pages. 91–94, ISSN 0002-7685, electronic ISSN 1938-4211. DOI: https://doi.org/10.1525/abt.2017.79.2.91.

specific instructional interventions (Crouch & Mazur, 2001; Deslauriers et al., 2011; Hake, 1998; Hoellwarth & Moelter, 2011; Hoellwarth et al., 2005; Marbach-Ad et al., 2010; Pollock, 2004). Although these assessment instruments were developed primarily for research purposes, we found the incorporation of existing assessment instruments into instruction to be an effective and relatively easy starting point for faculty to improve their practice.

○ Course Context

At the time of the study, the second author was teaching a nonmajors biology course at a community college in the Midwestern United States. According to the institution's website, the course is a survey course of how life functions and adapts on earth. For the purpose of this paper, we will focus on only one unit during the course of the semester, evolution and natural selection. Before PAR, the second author was teaching this unit using traditional lecture methods. She typically showed a video regarding Darwin's finches and then presented a PowerPoint presentation covering the history of research on evolution, artificial selection, natural selection, evidence for evolution, and population genetics. Her assessment was limited to evaluating student understanding of evolution and natural selection through a quiz, an end-of-unit exam, and a final exam.

A problem with these types of post-assessments is that, although they showed the second author where her students were at the end of the unit and course, they didn't take into account what students already knew or didn't know—that is, they didn't help her understand how students' understanding had changed as a result of her teaching. For this reason, when the second author and the first author met for their initial collaboration, we suggested that the CINS (Anderson et al., 2002) might be used to identify students' initial (mis)understandings about evolution and natural selection. However, similar to previous studies (Vanmali, 2012), the second author realized she could already identify common student difficulties, and that a diagnostic purpose might not be the best use of the instrument. Some of the common misconceptions that the second author was aware of included: population growth isn't stable; organisms have unlimited resources; organisms cooperate, they don't compete; there is very little variation in a population; traits that do not benefit organisms are not heritable; biological fitness is related to strength, speed, or intelligence; genetic mutations occur to help individuals; and organisms want to change over time.

To understand how the CINS might be effectively incorporated in the second author's classroom, we engaged in PAR. PAR is a research and professional development collaboration between individuals with different expertise that allows for faculty to be actively involved in course and curricular reform (McIntyre, 2008). In this case, the first author's expertise was in science education, and she was interested in reform in undergraduate science education. The second author was the instructor of the course and is therefore an expert in the content and curriculum of the course, and familiar with the student population and institutional reforms. PAR is useful to investigate one's own teaching, but the outcomes of the collaboration can also be useful to others. In the sections that follow, we share two outcomes of our PAR that can inform the efforts of other faculty interested in using assessment instruments to support teaching and learning.

○ An Alternative to Lecture

After discussing the second author's goals for instruction, we looked at the CINS to discuss how it might be incorporated into her instruction. She decided that the CINS could be used to develop a learning activity to engage students in discussing the questions and could "help clear up misconceptions." She planned to show the video of Darwin's finches that she normally uses, but instead of simply lecturing over the material, she decided to give an in-class worksheet with questions from the CINS to assess the students' understanding of natural selection (Appendix A; see http://www.drury.edu/academics/undergrad/science/biology/pdf/presley_app.pdf). During the activity, the students had difficulty answering the questions, something the second author hadn't planned on. In response to the students' confusion, she walked them through the questions from the CINS and explained why one answer was correct and the other answers were incorrect. Using the CINS questions allowed the second author to receive immediate feedback from the students about their understanding of the material, and to address that in-the-moment. Incorporating the CINS questions into the class discussion activity not only allowed the second author to assess her students' understanding, but also provided a learning opportunity for the students.

○ Addressing Student Difficulties through Labs

To further address the students' difficulties, the second author also wrote a lab based on the CINS. Before being introduced to the CINS, the second author used a lab on evolution published in a lab manual the institution used. The goals of the lab were to understand how the fossil record, comparative anatomy, and molecular biology could be used as evidence for evolution. To reach these goals, the biology department asked students to observe fossils, observe differences between a human and chimpanzee skull, and simulate antibody-antigen interactions in blood samples from different species. The assessment for this lab included a series of questions related to the content of the lab. The second author was not satisfied with the goals, procedures, or the assessment for the lab, so she incorporated questions from the CINS to assess a lab she wrote. The goal of the second author's new lab was to create a model of natural selection in which the students acted as birds with simulated beak types to determine which beak type was more adapted to a particular food source. After multiple generations of certain phenotypes "dying" in the population, the class was able to calculate how the allele frequencies had changed over time. At the end of the lab, the second author provided questions from the CINS to assess the students' understanding of natural selection. The second author's lab is now published in the lab manual the biology department uses throughout the institution (Appendix B; see http://www.drury.edu/academics/undergrad/science/biology/pdf/presley_app.pdf).

○ Lessons Learned

The purpose of our PAR was to explore how existing assessment instruments could be incorporated in a college science classroom to support teaching and learning. Our collaboration illustrates how assessment instruments can be useful in helping science faculty not only *assess*, but *address* student misconceptions. Research shows assessment instruments have primarily been used to reveal student ideas about a topic, help students be meta-cognitive, and study the effectiveness of various instructional strategies (e.g., Crouch & Mazur, 2001; Deslauriers et al., 2011; Dori & Belcher, 2004; Hoellwarth & Moelter, 2011; Hoellwarth et al., 2005; Pollock, 2004; Vanmali, 2012). Thus, our work contributes to the field by demonstrating potential ways that assessment instruments can be a tool for science faculty—at the college as well as high school levels—to guide the development of learning activities and laboratory exercises that target common areas of student difficulty. Rather than being used as a summative assessment to evaluate students, we used questions from the CINS to support students in developing their understanding. This is important because the CINS was used as a formative assessment, not merely as a summative assessment. Formative assessment is defined as "all those activities undertaken by teachers and/or by their students, which provide information to be used as feedback to modify the teaching and learning activities in which they are engaged" (Black & William, 1998). Assessment becomes formative when it informs instruction.

The use of formative assessment has been shown to improve student learning (Black & William, 1998). Since formative assessment is linked to improved student learning as well as pedagogical decisions (Crooks et al., 1996), it is clear that formative assessment tools and practices could enhance teaching and learning in the science classroom. However, it is not easy to design assessments tools and implement them in ways consistent with formative assessment. Given that faculty do not have access to adequate pedagogical training in graduate school (DeHaan, 2005) or from professional development workshops (Erickson, 1986), it is unreasonable to expect faculty to be able to design and implement their own assessments tools—particularly when high-quality assessment tools that are valid and reliable measurements of student learning already exist.

Even though the purpose of this paper was to highlight how a science faculty member used the CINS to create learning activities and labs that address student difficulties, ours and other studies (e.g., Vanmali, 2012) suggest that science faculty can use assessment instruments in other ways. Vanmali (2012) found that experienced instructors may use assessment instruments to confirm what they already know about student difficulties and to encourage students to be meta-cognitive about their learning. In our study, the second author used other assessment instruments, such as the Genetics Concept Inventory (Bowling et al., 2008), to incorporate higher-level thinking questions into her instruction and assessments. The second author also found assessment instruments in planning lectures. After reading the journal articles with assessment instruments and the associated research on student misconceptions, the second author had a better understanding of the common misconceptions related to topics, and incorporated these into the design of her lecture. Based on the information presented in this paper, we believe high-quality assessment instruments can be useful resources for science faculty. These instruments have been developed through a rigorous process to ensure validity and reliability. In this sense, we can be confident in the quality of the items and their ability to assess what is intended.

○ Recommendations

Although our work illustrates that assessment instruments can be useful to faculty, we also share some recommendations from our collaboration for those interested in these approaches. First, we recommend faculty read the published literature about the assessment instruments and their development. The second author found these particularly useful in understanding student misconceptions about a topic as she was preparing for lecture so that she could anticipate student areas of difficulty with the concepts. This required some time and advanced planning, so we also recommend that faculty who are interested in using assessment instruments search the literature and select the assessment instruments well in advance while planning their courses. Locating the specific instrument you want or translating the questions into accessible formats may take time as well. Additionally, we found not all the questions on the instrument met our goals; therefore a third recommendation is that faculty consider defining (or in some cases redefining) their course and unit goals as part of the process of aligning the assessment items with their needs.

We also recommend that science faculty review their current practices and begin to incorporate assessment instruments within those practices, instead of trying to make radical changes. For example, if a science faculty member currently uses only those summative assessments with lower-order thinking questions, substituting some of those questions with assessment instrument questions can provide a more valid and reliable assessment as well as replace recall questions with higher-order thinking questions. If a science faculty member is interested in incorporating more formative assessments into instruction, but is unsure of how to develop a formative assessment, using questions from assessment instruments may be an easy place to begin.

With this in mind, using assessment instruments to develop learning activities may be inconsistent with the goals of researching student learning. That is, pulling out specific questions for use in supporting student learning can compromise the later use of the instrument for research purposes. However, even the authors of the CINS encouraged teachers to use the instrument to facilitate student discussion. The authors stated, "Occasional use of selected items in [student discussions] always generates lively and highly productive discussion with nonmajors. The questions serve as an easy to use format for getting students to think about what they know, so that new information can be compared to prior knowledge, and the stage is set for conceptual change" (Anderson et al., 2002). In summary, assessment instruments can be a useful tool for purposes other than conducting educational research—they can provide a useful scaffold for faculty in building on their assessment knowledge and practice.

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