

Article

Development of Embedded Assessments for Learning in Biotechnology[§]

RESULTS AND DESIGN PROCESS FOR DISSEMINATION

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Embedded assessments, tasks within the context of instruction, can serve as important tools for improving teaching and learning. In this article, we report on the assessment design principles and a nine-step development model that guided the construction of innovative embedded assessments. Using multiple sources of data—expert reviews, a conceptual test blueprint, student interviews, focus group interviews, and student responses to assessments—we were able to analyze the extent to which our assessments align with research-based design principles. Specifically, our results demonstrate that the assessments: (a) align with learning and instructional goals; (b) are cognitively challenging; (c) support student learning; and (d) have reduced potential bias. These assessments were developed in the context of an introductory biochemistry course for nonbiochemistry majors with learning goals in areas of: scientific content, socio-scientific issues, and evidence-based decision making skills. The assessment design principles and development model are generalizable to other science disciplines. We discuss how the application of these design principles can generate valid and reliable embedded assessments that can be integrated into a modern classroom.

Keywords: Assessment and the design of probes for student understanding and learning, biotechnology education, teaching and learning techniques methods and approaches.

In the era of rapid advances in biotechnology, students will need to develop critical thinking skills to make informed decisions. For instance, to make a choice of whether or not to purchase genetically modified food, one needs to understand scientific principles, evaluate alternatives, and critique evidence [1, 2]. Critical thinking includes abilities to (a) identify issues, assumptions, and problems in an argument; (b) evaluate credibility and determine relevance of evidence; (c) make data driven inferences; (d) construct evidence based decisions; and (e) evaluate significance of decisions [3, 4].

Critical thinking assessment resources are lacking for all topics (e.g. cloning, genetic testing, genetic modification, and forensics) in the area of biotechnology. Biotechnology refers to the process of using living systems to make products or improve other species. Specifically, we refer to biotechnology as applied biological sciences and it draws on knowledge obtained through the field of biochemistry, genetics, and microbiology as well as other bi-

ological science and engineering fields. Assessments that are embedded within instruction can serve as tools to improve science teaching and learning for understanding [5]. Embedded assessments (EAs) refer to activities that provide opportunities to assess student performance, are incorporated within course content, and are indistinguishable from typical instructional tasks [6]. An exemplary EA (Snowball the Cat) developed by this project is shown in the Supporting Information. This assessment, like the others that were developed, clearly illustrates the design principles and processes that were used for creating quality EAs for biotechnology.

The main purpose of this article is to illustrate a design process for constructing quality EA for biotechnology, such as the example provided, and to demonstrate the effectiveness of these EAs on students' critical thinking as a result of the design process.

Current trends in science education address the inclusion of socio-scientific issues into the modern science classroom [7]. The National Science Education Standards promote the enhancement of students' decision making skills regarding socio-scientific issues at the K-12 level [2]. At the college level, recommendations include interdisciplinary curriculum and improved assessment practices for biological science courses to promote problem solving skills of students to solve real-world issues related to biological sciences [8, 9].

[§]Additional Supporting Information may be found in the online version of this article.

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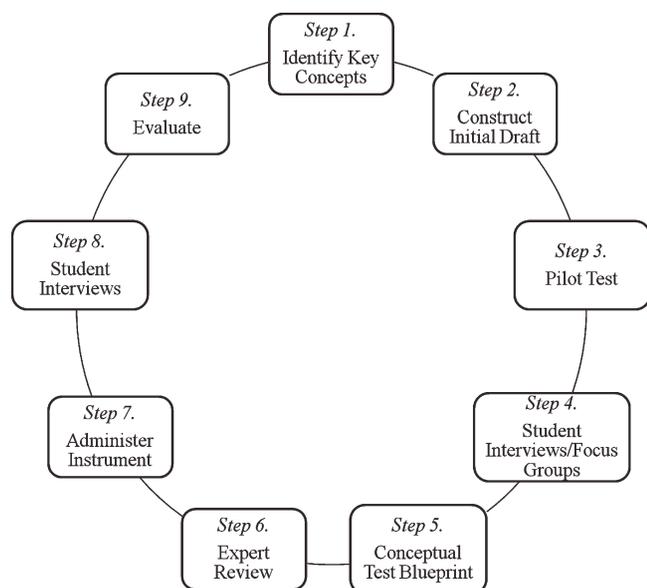


FIG. 1. Development of embedded assessments.

To enhance student understanding and decision making skills, it is imperative for assessments to be purposefully designed as tools for learning rather than just assessments of learning. This distinction stems from the basis that assessments for learning promote student learning (e.g. formative assessments). Assessments of learning simply serve as evidence and reporting of student achievement (e.g. summative assessments) [10]. To impact students' science understanding, valid and reliable assessments are needed [11]. By applying research based principles to frame the assessment design process, assessments can be greatly improved [12, 13]. Prior studies implementing such a design process have demonstrated the effectiveness of science assessments [14, 15]. The development of EAs was guided by four design principles, that assessments should (a) address learning and instructional goals, (b) be cognitively challenging, (c) support student learning, and (d) reduce potential bias for students [14]. Details of each assessment design principle are discussed in the corresponding results section of our EAs.

RESEARCH QUESTIONS

The overarching project goal included developing a set of innovative assessments to foster and effectively measure student learning in biotechnology-related courses. This article focuses on designing EAs. Our main research question is, "To what extent do the assessments align with our design principles?" Specifically,

- To what extent do the assessments address learning and instructional goals?
- Do the assessments challenge students to think critically? How?
- Do the assessments support student learning? In what ways?
- Do the assessments consist of any bias? In what ways?

To address the above questions, we collected and analyzed data from multiple sources—expert reviews,

conceptual test blueprints, student interviews, focus group interviews, and student responses to assessments.

METHODS

Course Contexts

We developed the EAs within the context of a large enrollment biochemistry course for undergraduate nonbiochemistry majors. At the same time, the EAs were developed with an eye toward future dissemination to a wider audience in other course contexts. The instructional goals of the course included: (a) helping students construct scientifically accurate ideas, and (b) enhancing their reasoning skills to make evidence based decisions about controversial issues in biotechnology. Four main ideas were predominantly discussed in the course: fundamentals about how cells work, stem cells, Mendelian genetics, and tools of the genetic engineer. Assessments were designed to assess and promote accurate scientific understandings and the application of those understandings while making informed decisions in case scenarios. The course structure included interactive lectures, case discussions, hands-on activities, and independent projects. This course used online readings and interactive websites, but no textbook.

Assessment Design Approach

We developed the EAs in nine steps (Fig. 1) lasting over one calendar year, adapting procedures defined by Treagust [16]. Although this methodology was originally developed for diagnostic tests, we adapted it to our EA development. The steps, which are in Fig. 1, can be cyclic for any future EA revisions.

We summarize the recommended steps of our assessment development model below:

- Step 1: For an assessment to be useful, it is essential that the concepts being assessed are identified [17]. To identify such concepts, generate a table to match guiding concepts (e.g. course learning goals and national standards [8, 9]) and course topics. Reviewing various biotechnology course syllabi to further identify important scientific concepts and research literature to identify known misconceptions in biotechnology may also be useful (e.g. [18, 19]).
- Step 2: Create and refine the EAs to address one or multiple concept(s). All EAs should align with existing instructional activities.
- Step 3: Administer and collect responses to the EAs. Analyze responses to ensure clarity and correct interpretation of the questions.
- Step 4: Conduct individual and/or focus group interviews to better understand why students performed the way they did. Interviews can be conducted to investigate students' understanding of biotechnology concepts and learning approaches. Also to investigate students' reactions to specific questions, question types, and how students' study habits, preparation, and skills affected their performance.
- Step 5: Establish content validity by constructing a conceptual blueprint (please see supporting materials) to display the range of learning goals and learning objectives (e.g. Bloom's taxonomy [20]) addressed by each EA and to serve as a development guide for each EA. It is essential that questions from each EA match the relevant guiding concepts and learning objectives [5]. The blueprint indicates alignment between assessment questions, content topics and learning behavior to reflect whether the assessment is balanced across concepts and objectives. Questions can then be refined, removed, and/or added.
- Step 6: Request biotechnology experts to review EAs for validation in relation to the EAs instructional and learning goals, complexity, promoting critical thinking, equity for underrepresented students, and clarity of questions. For content analysis provide reviewers with guiding concepts

TABLE 1
Inference of evidence and conclusions rubric

0	Does not provide any evidence. Just repeats the question.
1	Provides justification for the inference or conclusion, but (a) does not provide scientific evidence, only personal opinions or moral/ethical issues or (b) includes scientific information, but is inaccurate or irrelevant. Does not make a convincing argument.
2	Explains inference or conclusion using some accurate scientific evidence. May mention personal opinions or moral/ethical issues.
3	Clearly explains the inference or conclusion using scientific information that is mostly accurate and most pieces of evidence are analyzed. May incorporate and explain relevant personal opinions or moral/ethical issues.

to assess whether any learning goal is missing or needed to be rephrased. The EAs and guiding concepts can be further refined based on expert feedback.

- Step 7: Readminister revised EAs. Analyze student responses to ensure the clarity and intended interpretation of the questions.
- Step 8: Conduct semi-structured interviews with selected students to investigate their conceptual understanding and perceptions of the revised in-class assessments from students with varying backgrounds and classroom performance.
- Step 9: Based on results from student responses and student interviews, further refine EAs as necessary.

Analysis of Student Responses

To determine if our revised (Step 7) EAs improved students' critical thinking, we analyzed their responses to an EA that was administered at the beginning of the course and another EA that was administered toward the end of the course. One question from each EA was selected for our analysis. Because the assessment questions for the two EAs were designed such that students construct inferences and conclusions from evidence—an aspect of critical thinking—these aspects were analyzed. To analyze students' inferences of evidence and conclusions to the assessment question, a rubric was constructed to score responses for both EAs (Table I).

Out of approximately 118 students, 85 students completed both pre and post EAs which were analyzed using a paired *t*-test analysis to determine if there was a significant mean difference between pre and post EAs.

RESULTS

The results of our EA developmental process are organized into five major sections. We first begin with a description of our developed EAs. By using the results of our multiple data sources, we next address the extent to which our assessments align with each design principle—address learning and instructional goals, cognitively challenging, support student learning, and reduce potential bias. To protect participant identity, all names have been changed to pseudonyms.

Embedded Assessments

We developed a total of seven EAs during our study; which are available on our project website (<http://web.misouri.edu/~siegelm/DIALB.html>) along with a full description of our methodological development of these assessments. Also an EA—Snowball the Cat—is provided in Supporting Information. Table II provides an overview of the EAs, all of which were reviewed by the expert reviewers.

TABLE II
Sample of embedded assessments developed

Embedded assessment	Key concepts	Brief description
Ballot measure in Missouri Constitutional Amendment 2—stem cell initiative	Scientific literacy; educated decision making	Review a constitutional amendment and view two stem cell campaign ads about stem cell usage in research. Then evaluate the scientific information, explore society's impact on biotechnology, and make informed decisions.
Biotechnology steps: ideas to products	Scientific literacy; Modern biotechnology techniques.	Read a selected report in which a new product/organism is created through modern biotechnological techniques. Then think critically about the science and reflect on how this may affect society.
Bt Corn—to plant or not to plant?	Benefits and risks of BT crops.	To practice decision making skills by formulating alternatives, evaluating evidence, and deciding on a choice.
Clonaid on CNN	Biotechnology's impact on society.	Read a real advertisement from a company with false claims. Then, practice evaluating evidence and making evidence based decisions regarding cloning.
Genetic Disorder Homework	Inheritance of genetic variation.	To investigate a genetic disease/difference that runs in their family, and research information about their findings. Then submit a one-page report addressing the assignment requirements.
Snowball the cat	DNA as an identifier; statistics of forensics	To reflect on the science of DNA and of the biotechnology-related tools used in forensics. Then formulate opinion based on scientific evidence and values.
Stem cell therapy game	Differences between reproductive cloning and therapeutic cloning	To engage students in understanding stem cell therapy technologies—somatic cell nuclear transfer or <i>in vitro</i> fertilization.

We implanted prompts within EAs to encourage students to rethink the problem and recognize or generate alternatives, evaluate scientific evidence and opinions/values, and construct a decision based on evidence and alternatives. Examples of such prompts within an EA—Snowball the Cat is provided in the Supporting Information. In this particular EA, Snowball the Cat, students must reflect on the evidence provided in the article and relate their responses to what they know about the science of DNA and biotechnology tools used in forensics. They also practice formulating opinions based on evidence and values.

Address Learning and Instructional Goals

To attain quality classroom assessments, learning and instructional goals need to be addressed. Specifically, assessments should match the instructional style and language used within the course and should target the knowledge and skills outlined by the conceptual goals [21]. For instance, if the pedagogical practices employed in the course encourage students to make evidence-based decisions, then the assessments should also encourage students to make evidence-based decisions.

To confirm whether the EAs aligned with the intended learning and instructional course goals, we constructed a conceptual test blueprint (please see supporting materials). In the conceptual test blueprint, all EAs questions matched their intended goals with the appropriate guiding concepts. For instance, Ballot Measure was designed to be implemented during instruction about the role of stem cells in society and to encourage evidence-based decision making. Ballot Measure was designed with the aim to address a broad range of critical thinking skills including: demonstrating scientific understanding of stem cells to evaluating the issues of stem cells in society using multiple arguments and data sources. Snowball the Cat on the other hand was designed to address the use of DNA as an identifier in forensics. Again, Snowball addresses a broad range of critical thinking skills with varying guiding concepts that relates to genetics, genetic inheritance, biotechnology benefits to society, etc.

Our goal was not only to create EAs that address the assessment needs for our course, but to create assessments that can be adopted for use in other biotechnology related courses. Thus, the assessments should address learning and instructional goals of other biotechnology courses. All expert reviewers indicated that the assessments would be useful to them in their courses. A reviewer, Dr. Parker, noted:

“They seem to do an excellent job of leading the students to gather facts and think about them critically. I particularly like the fact that the students are taught to evaluate sources critically. That’s something I try to incorporate in my classes wherever I can.”

Dr. Howard commented, “I see them as very useful to our program. I likely would use a major portion of them to both guide our instruction and direct our assessment.” Also Dr. Foster mentioned, “These assessments are more aligned with the approach that I use, although I draw more heavily from the primary literature.” All six

expert reviewers provided similar comments suggesting that the EAs aligned with their instructional and assessment goals.

After analyzing pilot test responses from students and expert reviews, we made minor modifications to ensure that questions elicited intended learning goals for each EA. For example, an original question in Snowball the Cat was: “Do you think it is possible to prove that cat hair came from a specific cat? How would scientists do this?” A typical student response such as George’s was, “Yes, test the DNA to match using the hair in the coat and a sample from Snowball.” However, such a response does not demonstrate a clear understanding of the biotechnology steps for DNA profiling. Therefore, this question was rephrased: “Do you think it is possible to prove that cat hair came from a specific cat? How would scientists do this? Explain the steps of the process.” This modification was made to elicit specific knowledge about DNA.

Cognitively Challenging

Assessments should be cognitively challenging by promoting critical thinking skills. Involving students in evaluating their own work can engage students with more difficult assessments. Students are better able to make connections between ideas if given opportunities to reflect on their learning [22].

To ensure the EAs are cognitively challenging for the students, each EA needs to address a range of critical thinking skills requiring analysis and synthesizing information and evaluation of multiple sources of evidence, not just rote memory tasks. For instance, although the EA—Biotechnology Steps: Ideas to Products, addresses multiple guiding concepts, its questions addresses a broad range of critical thinking skills, including evaluation of evidence as reflected in the conceptual test blueprint.

Analysis of expert reviews indicated that six out of the seven EAs supported critical thinking across a broad range of key concepts. Dr. Parker wrote,

“Yes, most definitely. They have just the right amount of structure to make students consider multiple questions and points of view that might not occur to them independently.”

Also Dr. Cooper wrote,

“These are innovative assessments that challenge the student to think and put their knowledge in perspective. A broad range of topics is covered. The presentations are straightforward and well organized.”

Reviewer comments suggest that the combination of EAs do address a broad range of topics and are structured such that prompts provide students opportunities to make various connections with the science. In essence, the EAs challenge students to think critically.

Ballot Measure was the one exception in which all of the reviewers did not agree that students were critically challenged. Two of six reviewers indicated that this EA did not challenge students enough to think critically, such as it did not provide enough opportunities to evaluate scientific information and explain reasoning.

Therefore, we revised the EA by adding questions, as well as incorporated open-ended/explain prompts to existing questions to elicit students' reasoning. An example of a revised question is: "Would this ad influence your vote? How? Why or why not?" The inclusion of How? and Why or why not? was purposefully added to the original question to further elicit and probe students' understanding and use of evidence to support their opinion.

In contrast, the EA, Stem Cell Therapy Game, was identified by the reviewers as an assessment supporting critical thinking. Reviewers acknowledged that questions within this particular assessment required students to reflect upon other sources of information to construct an evidence-based response. An example question is: "If you heard on the news that a scientist took a cloned stem cell made through SCNT (somatic cell nuclear transfer) and implanted it into a woman's uterus and it developed into a baby, would you believe the reporter? Why or why not?" A typical response to this question from students such as Lillian was:

"No. First, this has not been tested in humans yet and it is not likely that it would be successful on the first try. Second, the baby would be a clone of the woman. Cloning is illegal in many places and is considered unethical by some. SCNT cells also do not have the ability to form the placenta that would be required for the development of a baby."

In this type of justified response, Lillian does consider multiple sources of evidence, such as knowledge about SCNT testing, legal issues regarding SCNT, and cell development from using SCNT, if she was to consider believing a news report.

To further examine the extent to which the EA are cognitively challenging, a paired-samples *t*-test was conducted, at $\alpha = 0.05$ level of significance, to compare scored responses to a selected question on the pre EA and post EA. The test showed a statistically significant difference in the scores for pre-EA ($M = 1.4824$, $SD = 0.89458$) and post-EA ($M = 1.9882$, $SD = 1.00587$) conditions; $t(84) = -3.547$, $p = 0.001$. The Cohen's effect size between student scores on the pre EA and post EA was $d = 0.531$ which is considered to be a medium effect size [23]. These results suggest that the EAs designed in this study have a significant effect on students' critical thinking. Specifically, our results suggest that as students responded to EA items throughout the course their critical thinking skills improve, thus the EAs are cognitively challenging.

Support Student Learning

Assessments should also support student learning. Scaffolds like graphic organizers or additional prompts, often used in quality instruction, should be built into assessments (e.g. [14, 24, 25]). By incorporating scaffolds into assessments, students can better understand what is being asked, think about the concepts and appropriately respond to assessment prompts.

Experts' responses suggested that the EAs support student learning and that students can gain valuable insights from these assessments. Experts recognized

that prompts to encourage students to evaluate evidence to make an informed decision are a useful feature of the EAs. Dr. Lewis noted, "I expect that students would learn about applications of the technology with which they were unfamiliar. Also learn how to evaluate information coming from a variety of sources, including the internet." Another feature frequently noted by reviewers was the structure of the EAs. Dr. Parker elaborated:

"I think the students would learn a great deal, including the following: (a) the assessments are very thorough and structured. I think this carries an implicit message that these are the kinds of questions that students should be asking about articles that they encounter outside the class, (b) the assessments definitely teach critical thinking, and (c) the assessments will most likely help students take their book knowledge of biochemistry and biotechnology and weave it together into a more coherent whole, because they will be applying it to real-world situations. Again, the fact the assessments are so structured is good."

To successfully support student learning, EAs need to be structured such that the necessary scaffolds and prompts are provided. Both Drs. Lewis and Parker's comments suggest that the EAs do indeed provide the necessary structure.

As another example, reviewers also identified the EA, Biotechnology Steps: Ideas to Products, as supportive of learning. The purpose of this EA is to explore possible uses of biotechnology in varying contexts by reading a story, report, etc. (e.g. [26]). An example question is: "Explain this article using the four steps of modern biotechnology." A typical response from students like Ethan is: "1) select the gene you want to use—fibroblast cells from sea anemones, 2) clone gene—clone fibroblasts, 3) transfer gene—transfer the clone fibroblasts in dog cell, and 4) identify new gene—glow red under ultraviolet light." In this question, it is desired for students to relate the concept of modern biotechnology steps for product creation to a real-world application, which is indicative in Ethan's response.

Individual student interviews indicated that students appeared to have their own preference about which EA helped support their learning or critical thinking. These preferences seem to be based on information most relevant within instructional and societal contexts. For instance, one student, Olivia, preferred the EA Stem Cell Therapy Game:

"The Stem Cell [Therapy Game], we played, not a bingo, but you would roll the dice and you would move it, and on one side was *in vitro* and on the other side it was a somatic cell nuclear transfer. It just helped, even if I did not get it then when I was studying for the second test, I could go back to that and be like "oh my gosh." I think I probably would have failed the second test if it was not for it actually. It just helped me so much; I was surprised like "that makes so much sense, this piece of paper."

Another student, Jake, instead preferred the EA Snowball the Cat:

"I feel like I learned the most in that because it almost relates to what we do in everyday life. Not like we actually do that but we watch CSI and NCIS and all of those different shows. I just feel like it was easier to relate to."

To support student learning, assessments should match the instructional style of the course. One course objective is to connect scientific concepts with societal contexts. Jake's comment exemplifies that EAs allow students to make such connections.

Focus group participants acknowledged the usefulness of the EAs for the topics being discussed within class, but they also indicated that the individual student background must be considered. When asked to comment about the effectiveness of integrating the assessments with instruction, Eddie commented:

"I know she is trying to relate the science to the activities. Some activities are going to be more useful and involving than others. Some applications are going to interest people more than others. Everyone is going to come in with different backgrounds; it is not all strictly science backgrounds, business based, or education. Everyone comes in with a different aspect."

Here, Eddie's response indicates that certain groups of students will appreciate certain assessments more than others depending on previous science courses taken and their personal background. This may also be indicative of why students, such as Olivia and Jake, preferred certain EAs over others. Thus, to support student learning, prompts should take students' experiences and backgrounds into account.

Reduced Bias

Finally, assessments should reduce potential bias to ensure that they are equitable and fair for all students [27]. It is important to identify and remove as much bias as possible; for example, the wording of an assessment should be considered carefully to avoid bias. Research has shown that when educators apply quality assessment strategies, low-achieving students can be positively impacted, thus serving an important goal in assessment practice [28].

To ensure EAs contained limited bias, reviewers were asked: "Do the assessments provide equal opportunities for groups of underrepresented students in the sciences? Groups include: race, language status, gender, disability, and first-generation college." Overall, all six experts responded that they did not perceive any such bias within the assessments. One potential exception was noted by Dr. Shaw concerning an EA—Genetic Disorder Homework. This particular assessment requires the student to interview a family member or someone they know who has a genetic disorder or difference and then submit a report about their findings including information about the genetic disorder and family pedigree. "I find it uncomfortable to look into one's own family for a disorder. Is it necessary to use a disorder, which may be sensitive?" The reviewer expressed concerns that reporting about a genetic disorder in one's family can be a sensitive topic for certain individuals. However, the assessment can be adapted such that students can investigate other hereditary traits that are less sensitive to discuss.

SUMMARY

"I especially like the embedded assessments. Not too many materials like them are available" says Dr. Lewis.

This quote underpins the need for innovative assessments in biotechnology at the college level. A long-standing goal concerning assessment development is that assessments should match the instruction [5]. To construct effective classroom assessments, assessment design should be rooted in four design principles, such as those we employed: address learning and instructional goals, be cognitively challenging, support student learning, and reduce potential bias for students. The use of research-based design principles is important for effective assessment development, yet these design principles are underutilized by educators and materials developers.

To construct EAs that integrate the four design principles, effective assessment development requires a developmental cycle approach with recursive research [29] for continual refinement. As proposed by Treagust's [16] instrument design framework, assessment design should include student interviews as the basis for assessment revision and refinement [29]. Also, the design steps should include identifying what is to be assessed in relation to learning goals, pilot tests, reviews by experts or instructors, and evaluation for revision and refinement over time. This study provides a framework and model for developing EAs, as well as findings showing that the EAs meet the design and validity criteria.

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