A Field Guide to Constructivism in the College Science Classroom: Four Essential Criteria and a Guide to their Usage

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Abstract: This field guide provides four essential criteria for constructivism as well as a guide for using these criteria to identify and assess the level of constructivism being used in an educational experience. The criteria include: 1) prior knowledge, 2) cognitive dissonance, 3) application with feedback, and 4) metacognition. This guide provides timely, valuable information and "best practices" for science educators, especially faculty in higher education.

Key words: constructivism, prior knowledge, biology teaching, cognitive dissonance, metacognition, science pedagogy.

INTRODUCTION

Constructivism has become one of the most important learning theories in modern education. It is the basis of inquiry teaching methods, and consequently it is the primary learning theory underlying the AAAS "Vision and Change in Undergraduate Biology Education: A Call to Action" (AAAS, 2011), the newly released framework for K-12 science educators ("A Framework for K-12 Science Education: Practices, Cross-cutting Concepts, and Core Ideas", National Research Council, 2011); and the research and findings that support them. Constructivism is also used as a theoretical framework for many educational research studies in biology (e.g. Anderson, 2002; Banet & Ayuso, 2003; Burrowes, 2003; Donovan, Bransford, & Pellegrino 1999, Eshel, 2007: Herron, 2009; Llewellyn, 2005; Shields, 2006; Yager, 2000).

In our practices, we have encountered numerous people who would benefit from a concise primer on the essential criteria of constructivism, but do not otherwise have a background in educational theory. We have worked with college and university instructors and faculty in biology and other sciences who were trained only in the STEM fields, as well as students, new teaching assistants, pre-service science teachers, and others who are being introduced to (and frequently asked to understand or even use) constructivism or constructivist teaching methods such as inquiry. This article provides an introduction to the vocabulary of constructivism, a concise, easy to understand, distillation of the theory of constructivism, as well as a portable rubric that can be used when trying to identify the constructivist elements of a real-life educational activity. This article thus meets the challenge of a recent Bioscene *Perspectives* article (Jensen, 2011) that called for enhancing the pedagogical knowledge of college and university biology educators.

Just as a mushroom hunter needs to be able to identify mushroom species without becoming a mycologist, a practicing science educator needs to be able to identify and assess constructivism to be able to promote its use. This article, based on the authors' previously published theoretical review article (Baviskar et al., 2009), serves as a field guide for identifying constructivism in the habitat of a college science classroom. So grab your checklist and hone your powers of observation while we describe the characteristics that will help you identify constructivist teaching strategies.

How to Recognize Constructivist Look-Alikes!

No field guide for mushroom hunting is complete without comparing edible Morels to deadly False Morels. Likewise, we first need to compare and thereby remove the confusion that arises from similar terms for different theories, specifically: "cognitive" or personal constructivism vs. "social" constructionism. Cognitive constructivism is a theory that describes learning as taking new ideas or experiences and fitting them into a complex system that includes the learner's entire prior learning. In other words, students arrive with pre-existing 'constructs,' and in order to learn, must modify these existing structures by removing, replacing, adding, or shifting information in them. Social constructionism is a sociological theory that describes how the facts that a society believes to be true are 'constructed' through social interactions (Baviskar et al., 2009, Longino, 1990; Marin, Benarroch, & Gomez, 2000; Richardson, 1984; Rodriguez, 1998). While *social constructionism* is an interesting theory and happens to share a similar name to constructivism, it is *cognitive constructivism* that can help us understand how our students learn.

Another confusion associated with constructivist teaching is the idea that constructivism requires the use of 'group-work.' Because of the importance of group work in many constructivist teaching methods, along with the confusion between social and cognitive constructivism, it is easy to equate constructivism with any kind of 'group-work' or 'talking amongst peers' (for an example of this confusion, see Straits, 2007; Straits & Wilke, 2007). Although cognitive constructivism can be effective in group-work, groups are neither necessary nor sufficient to make an activity constructivist.

One final 'look-alike' warning is the idea that constructivism is merely 'students doing whatever they want' in a completely unstructured classroom or lab. Constructivism is a student centered learning theory. It assumes that learning can only take place when students are actively engaging with the topic and 'constructing' their own knowledge bases. Because of this need for engagement, many constructivism-based teaching methods, like inquiry, use a lot of student directed activities. However, in order to be based in constructivism, a lesson must engage the motivations to build on the prior knowledge of the students (Bybee, 2002; Llewellyn, 2005), which involves much more than simply 'letting the students do what they want.'

Key "Field Marks" or the Identifying Criteria of Constructivism

The four criteria essential to identifying and assessing constructivism are as follows: 1) eliciting prior knowledge, 2) creating cognitive dissonance, 3) applying new knowledge with feedback, and 4) reflecting on learning (metacognition). Any given activity or lesson plan can be considered more or less constructivist depending on how many, and to what extent, the four criteria have been incorporated. Table 1 provides a summary of the four criteria, identifying characterisitcs, and an exemplar lesson from the published literature.

Eliciting Prior Knowledge

Learners 'construct' knowledge by modifying and contributing to their existing mental constructs. In the constructivist literature, this existing mental construct is succinctly referred to as 'Prior Knowledge.' Eliciting prior knowledge refers to any activity that both describes the students' prior knowledge for the teacher and also focuses the students' attention on those aspects of their mental constructs to be modified by the subsequent lesson. The teacher can use this description of their students' prior knowledge to fine-tune the lesson. Maybe one class needs to focus on a single basic concept, while another class may be able to skip ahead to applications of the concept. Also, if the students don't know where the lesson is supposed to 'fit' into the rest of their knowledge, they may simply memorize the lesson and then forget it after the quiz, or worse, try to fit the information improperly into the wrong topic, creating misconceptions.

When observing a lesson to identify signs of constructivism, look for opening activities that emotionally and cognitively engage students in the topic at hand. The activity should encourage them to think about what they already know or to attempt to solve a problem in the relevant topic. Be wary of activities that simply check whether students have read their text, or done homework. Likewise, be wary of high stakes assessment tools or activities that contribute significantly towards a grade. Readings or

Table 1. Field Guide to Constructivist Teaching and Learning.

Four Essential Criteria	Field Marks: Expected methods & learning activities	Exemplar: Leaf decomposition in streams (Hopkins & Smith 2011)
1. Eliciting prior knowledge	Demonstration, problems, focused listing, surveys, quizzes, interviews, discussions, concept mapping. Emphasis on eliciting student ideas.	Present students with a fresh and a decomposed leaf. Have students draw and list the processes that they think contribute to the change in the leaf.
2. Creating cognitive dissonance	Uncover misconceptions, compare lists, discuss missing information, demonstration, create discomfort. Pose a controversial question, or state/write a surprising or counterintuitive statement	Compare student drawings and lists. Explore relevant variables in decomposition. Reveal gaps in knowledge of the process.
3. Application of new knowledge with feedback	Formative assessments, feedback on new constructs, hypothesis testing, gain of new knowledge. Focus on process of gaining new knowledge, solving problems, design & logic of analysis and presentations.	Generate testable hypotheses, design and carry out experiments to manipulate variables related to the process of decomposition. Data analysis and summary of results, with feedback.
4. Metacognition (reflection on learning)	Repeat Step 1 and have students reflect on their own learning. Assignments should have students explain variables, processes, or derive conclusions from evidence. Reflective paper, presentation, field report, peer teaching.	Repeat initial leaf exercise & compare with initial drawings. Have students reflect on their new knowledge through presentations in a scientific format.

vocabulary quizzes usually do not provide enough motivation for students to explore their prior knowledge and high stakes assessments often distract students by focusing on techniques for acquiring points. The most constructivist activities are going to force the students to access and apply their prior knowledge in a way that can be observed and interpreted by the teacher. Demonstrations can be useful if they actually engage the students. Having students try to solve a problem or explain some data that has not yet been covered; conducting open-ended discussion of background knowledge, focused listing or informal surveys about students' concepts of the topic, and short discussions about the topic through current events or applications to the students' lives all can help elicit prior knowledge (Donovan, Bransford, & Pellegrino, 1999; Leamnson, 1999).

Creating Cognitive Dissonance

If the students' constructs are different from the teacher's and the students do not realize it, or do not try to change them, no learning will take place regardless of how the lesson is taught. Only when the students realize that their prior knowledge is insufficient or inappropriate to understand something will the students become motivated to modify their constructs. The realization that their current constructs do not match their needs is called cognitive dissonance, and it is often as uncomfortable as it sounds.

To identify cognitive dissonance, look for wrinkled brows. When students are presented with information or puzzles that their current constructs cannot account for, they often look confused. Misconceptions are another sign that students' constructs are inappropriate for the problem at hand. Constructivist lessons often seek out misconceptions and then present problems that the misconception cannot address. If the teacher presents information that doesn't match the students' prior knowledge and then says something similar to, "How do you account for this?" or "What is the evidence for this observation?" he or she is likely trying to create cognitive dissonance in the students.

Modifying a mental construct is difficult. In order to learn, neural connections must be broken and remade which takes time, uses energy, and requires effort. Cognitive dissonance is an emotional discomfort intended to motivate the physical effort required for learning (Leamnson, 1999; Zull, 2002). Too much cognitive dissonance, however, and the student will stop focusing on the lesson and instead focus on removing the emotional discomfort. Too little, and the student will not be motivated to modify the erroneous prior knowledge. Therefore, constructivist lessons tend to have variable activities and constructivist teachers tend to shape their lessons to find an optimum level of dissonance for each particular class.

Application of New Knowledge with Feedback

Creating cognitive dissonance and motivating students to modify their constructs does not guarantee that the students' new constructs match the goals of the teacher, only that the students have reconciled a single challenge to their constructs. Next, the students need to apply their new constructs to a variety of other puzzles or information to find out if the new constructs really work. Application of new knowledge has two main functions. First, it is a test and fine-tuning of the new construct. Second, it is repetition using multiple perspectives that helps to reinforce the learning. To accomplish these functions, it is important that the students receive both appropriate learning activities and feedback for their work. Grades by themselves usually don't provide enough detailed or timely feedback to serve as formative assessment. Formative feedback, in a constructivist sense, requires explicit directions on the next misconception to be dealt with, as well as detailed explanations of past performance.

To identify application of new knowledge in a college science classroom, look closely at the learning activities. Proper application of constructivist principles will take place if students are given a series of problems addressing a topic from several angles, the topic of the problem series is related to a prior misconception, and the problems create cognitive dissonance. Questions that can be classified in the upper end of Bloom's Taxonomy (Bloom et al., 1956), critical thinking questions, case studies, and other more complex assessments are often used in 'application of knowledge' activities (Lord & Baviskar, 2007).

Appropriate, constructivist feedback is often found in detailed comments by the teacher for assignments or other assessments, but appropriate feedback can come in many forms. The teacher can give feedback by presenting one solution for a problem to the class in general. This presentation would give students something to compare their own constructs to. More importantly, truly effective feedback often comes from the students' peers or from the assignment itself. One of the places where small group interactions are very effective is in providing timely and relevant feedback. If the assignment involves performing a self-correcting activity, the feedback can come from the assignment itself.

Reflection on Learning or Metacognition

Metacognition is the act of thinking about your own thinking. Because constructivism is student-centered, students are ultimately responsible for their own learning. The more students recognize both what and how they are learning, the more efficient their future learning will become. Because learning takes time and effort in several topics or from several perspectives, the process may not be self-evident to the students. It is especially easy for students (and teachers) to misdiagnose a complex process of constructivist learning as simply inefficient memorization of another small fact. Reflection and metacognition will not only help the students understand the extent of what they have learned, but also help them to approach new learning in a more knowledgeable, and therefore efficient, way.

Metacognition can often be recognized when students are required to explain what they have done, how they did it, and why it was important. Reports, papers, presentations, and other discussions are a good sign that metacognition might be asked for. Look for questions or objectives that ask the students to explain a logical sequence or derive a conclusion from evidence, rather than to simply report what they have seen or done.

CONCLUSION

Our primary objective in writing this field guide is to provide the theoretical, research-based, essential criteria of constructivism in a way that can be used in an applied setting, such as a biology classroom. By presenting the four essential criteria of 1) eliciting prior knowledge, 2) creating cognitive dissonance, 3) applying new knowledge with feedback, and 4) reflecting on learning or metacognition, we hope to provide college and university biology educators and educational practitioners in general with an easily accessible guide to identifying and evaluating the use of constructivism in educational activities.

Our secondary objective is to open a dialog among educators, theorists, and researchers who wish to use and discuss constructivism, especially as they move to implement the new Visions and Frameworks called for by AAAS and the National Research Council. By using these four essential criteria, college and university science teachers will be able to evaluate their own and their colleagues' lessons, review curricula, and plan and evaluate educational research according to the principles of constructivism. They will also be able to use terms (like 'constructivism' itself) properly and to open a broader multidisciplinary dialog in the literature to discuss what constructivism really means from theoretical, experimental, and applied perspectives.

Finally, college science teachers, educational theorists, and educational researchers can all communicate about constructivism from their own perspectives, while using common language and ideas. Educational terminology is a lot like common names for species. Any terms can work if used by a small group of practitioners who understand each other's perspectives, but to cross disciplines and effectively read the literature, we need to have commonly held definitions and theories. So with field guide in hand, you can now examine and explore diverse publications and classrooms for your own glimpse of the constructivist lesson.

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