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A Mile Wide But Not An Inch Deep: Striving to Promote Deep Understanding and Learning in University Science Laboratories

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Summary

The typical undergraduate science laboratory session requires students to arrive prepared with an understanding of the methods and underlying theory of the experiment. In order to maximize the time-constrained nature of laboratories, Teaching Assistants (TAs) may expect students to have reviewed important key concepts, study questions, or lab methods prior to the session. A growing body of literature suggests students at all levels benefit from a curriculum that fosters 'deep understanding' and 'deep learning' in which students acquire the ability to make cognitive connections between concepts and to integrate new knowledge accurately (e.g., Leithwood, McAdie, Bascia, & Rodrigue, 2006; Hermida, 2014). The following workshop offers some tools to enhance student understanding and comprehension toward deep understanding in science laboratory sessions using lesson-planning strategies, including activating prior learning, incorporating applied examples and conceptual linkages, and checking for understanding.

Keywords

self-assessment, applied examples, knowledge organization, concept mapping, flowchart summaries, undergraduate science laboratories, deep learning

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SUMMARY

The typical undergraduate science laboratory session requires students to arrive prepared with an understanding of the methods and underlying theory of the experiment. In order to maximize the time-constrained nature of laboratories, Teaching Assistants (TAs) may expect students to have reviewed important key concepts, study questions, or lab methods prior to the session. A growing body of literature suggests students at all levels benefit from a curriculum that fosters 'deep understanding' and 'deep learning' in which students acquire the ability to make cognitive connections between concepts and to integrate new knowledge accurately (e.g., Leithwood, McAdie, Bascia, & Rodrigue, 2006; Hermida, 2014). The following workshop offers some tools to enhance student understanding and comprehension toward deep understanding in science laboratory sessions using lesson-planning strategies, including activating prior learning, incorporating applied examples and conceptual linkages, and checking for understanding.

KEYWORDS: self-assessment, applied examples, knowledge organization, concept mapping, flowchart summaries, undergraduate science laboratories, deep learning

LEARNING OBJECTIVES

By the end of this workshop, participants will be able to:

- incorporate applied examples into their pre-lab lectures in order to activate students' prior learning;
- implement strategies to enhance knowledge organization by helping students to link new and prior knowledge;
- reinforce laboratory skills by checking for understanding and comprehension throughout a teaching session (i.e., laboratory experiment); and
- practice interactive group work activities that engage students with each other and the course material, in order to guide comprehension, and produce deep understanding/learning.

REFERENCE SUMMARIES

Leithwood, K., McAdie, P., Bascia N., & Rodrigue A. (2006). *Teaching for deep understanding: What every educator should know.* Thousand Oaks, CA: Corwin Press.

In their examination of teaching for deep understanding, the authors of this book describe the conceptual framework of science teaching as sequential and reliant on the development of prior competencies that students build upon using increasingly more complex conceptual interactions. The authors examine the need for students to acquire deep understanding of discipline-specific knowledge areas alongside their existing knowledge and understanding of life outside of the classroom. Therefore, emphasis of deep understanding and learning in the science curriculum requires application using examples that students find relatable (such as personal experiences, current or historical events) in order to make connections to new knowledge. Newton (2000) suggests that achieving understanding in the sciences involves knowledge that is conceptual (relating fundamental concepts to prior knowledge), procedural (descriptive of how to do something), situational (identifying how and when to apply knowledge) and causal (recognizing how one idea affects another).

When students understand new material through their own thought processes (by accessing their understanding of the material alongside its application to life outside the classroom), they form strong conceptual linkages that serve as a substrate on which to build new knowledge. According to research reported from several studies cited in this text, the absence of applied examples is prevalent across the North American school system at all levels of education. As a result, the skill-sets of educators are trivialized and students are bored (Olson, 2005). The ability to link past knowledge and new knowledge successfully enhances the motivation to learn. This type of teaching requires the engagement of both instructors and students. Indeed, within the pedagogical approach of constructivism, the teacher's knowledge is a critical component to connecting relevant ideas to students' current thinking at appropriate points in the lesson (Nuthall, 2002). Evidence shows that among students, the strongest motivation for further learning is success with prior learning and the resulting self-efficacy experienced by the learner (Bandura, 1997). The authors cite Holt's (1964) seven-point list to assess whether students have attained a deep understanding of a concept, principle, or insight.

This workshop will draw upon some of the principles of teaching for deep understanding and learning. In addition, the workshop will demonstrate tools that help students to self-assess their comprehension and to consider practical application during lab sessions from the start of the session to activate their prior learning and throughout the session to check for understanding.

Ambrose, S.A., Bridges, M.W., DiPietro, M., Lovett, M.C., Norman, M.K. (2010). *How learning works: Seven research-based principles for smart teaching*. San Francisco, CA: Jossey-Bass.

This book explores seven principles of effective teaching and presents strategies to optimize student learning by understanding how learners process material and conceptualize information. Two of these principles are of direct relevance to this workshop. "*Student's prior knowledge can help or hinder their learning*" is one principle the authors cite in order to emphasize the distinction between the knowledge students have versus the knowledge educators expect them to have. They also explore a similar caveat that what students know can hinder them as much as what they do not know. The former is a consequence of misunderstood or misused prior knowledge that results in inappropriate associations and distortion of incoming knowledge. The authors present strategies to activate prior learning by encouraging students to self-assess their own level of understanding, while the TA evaluates the baseline understanding of the class. The authors refer to this process as appropriately 'calibrating' the material in order to address knowledge gaps. Evidence shows that students learn by linking new information with prior knowledge (Bransford & Johnson, 1972) and to do this effectively, they rely on the extent and accuracy of that prior knowledge.

In addition, students do not always spontaneously access their prior knowledge, emphasizing the important role of the TA in harnessing appropriate knowledge and addressing misconceptions and misunderstandings. Declarative knowledge (facts and concepts insofar as they can be recited, e.g., knowing the steps in an experiment) should be distinguished from procedural knowledge (understanding when and how to apply procedures/theories, e.g., knowing when to apply a formula, but not knowing its theoretical meaning).

Another principle the authors propose suggests, "*The* ways that *students organize their knowledge influences how they can learn and apply what they know*". This principle examines the difference in knowledge organization between novice and experts. A novice may organize their knowledge as a set of concepts without understanding the links and relationships between concepts (e.g., absorbing information from a lecture without connecting the information to applied practice in a lab session, or with themes across the course.) Another novice approach is to build sparse connections that are arranged in sequence (e.g., able to follow the steps of a lab method successfully but not able to apply them to different situations where a modified approach is needed). In contrast, expert knowledge organization is complex with many linkages and categories that lend to their comprehension and adaptability. Bower (1969) demonstrated that when given a long list of minerals to learn, students improve up to 350% if provided with criteria to help organize minerals into categories.

This workshop will draw upon principles and strategies described in this book for self-assessment to activate prior learning. The facilitator will use concept maps to bridge the gap between TA (expert) and student (novice) knowledge organization.

Gallagher, J.J. (2000). Teaching for understanding and application of science knowledge. *School Science and Mathematics*, 100(6):310-318.

In this review, the author examines the reform of science education in North America, focusing on teaching for understanding and the application of knowledge. Despite the apparent consensus that both teaching for understanding and application are critical to retention and science literacy, rote memorization persists in university classrooms and labs. This paper describes some of the teaching challenges associated with post-secondary science courses, namely the burden of effort on educators to learn and prepare a pedagogical approach that fosters active learning, alongside resistance from students to participating in a curriculum that requires introspection, analysis, and collaboration. The author examines strategies that would help to move science education away from a paradigm that he describes as merely helping students to amass information about scientific ideas rather than fostering understanding and application of these ideas beyond the classroom/laboratory. Gallagher cites a three-pronged approach to learning known as the 'Mercedes Model' which includes the traditional practice of building a knowledge base by conveying facts (lectures and readings), generating understanding by making connections (concept mapping, group work for collective understanding), and identifying applications (real-world connections).

The article also presents vignettes about condensation and inertia to illustrate the application of knowledge to real-life, relatable contexts. Gallagher notes that discussing simple examples related to familiar experiences can deepen understanding of theoretical concepts, elucidate common misconceptions, and significantly improve learning. The author also emphasizes the utility of embedded assessments throughout the teaching session to ascertain students' understanding *while* they are learning, and to help them make sense of information and difficulties *during* the learning process.

This workshop will draw upon the principles outlined in the Mercedes Model approach to teaching for understanding and knowledge application, including concept mapping, group work, and considering real-world applications and examples.

CONTENT AND ORGANIZATION

Facilitators should use a typical undergraduate laboratory experiment as the focus of the workshop in order to model teaching approaches in a specific context. Workshop participants (i.e., TAs) can adapt the activities for use in their own laboratory sessions. The Presentation Strategies section provides additional details.

Duration (min)	Subject	Activity	Purpose
5	Introductory Lecturette	Introduce the concept of deep learning/understanding including the definition and principles using the provided references. Share the workshop learning objectives and the format of the workshop with participants.	Provide participants with the context and objectives for the session.
10	Self-assessment Activity	List a set of terms related to the experiment on the board and have participants work in small groups to define a concept using the listed terms. Each group records their definition on the board and the collective group evaluates the accuracy of the definitions. An alternative approach would be to list definitions with common mistakes and ask the group whether they agree with the definition, and then address misunderstandings/ misconceptions. TAs can use these same strategies in their own laboratory sessions.	Activate prior learning through self-assessment and brainstorming. Self-assessments help students determine whether they are starting a session with a clear understanding of past material covered in lecture and readings. TAs can assess baseline knowledge and clarify inaccurate or incorrect information prior to starting the lab.

10	Applied Examples Activity	Show an image that represents a controversy, current topic, or historical event to discuss an applied example of the lab experiment. If images are not available, describe an example, analogy, or metaphor related to as the main idea, theme, or skill used in the experiment. The facilitator should clearly explain the relevance of the example. TAs will be able to employ this same technique in their labs.	Demonstrate integrated application and effective examples. Examples engage student interest and stimulate connections between prior and new knowledge. Students make connections that are more sophisticated when working with familiar contexts.
5	TA Reflection: Part I	Ask participants to reflect on the first two activities, and strategize ways to modify the activity or troubleshoot any anticipated issues. This could be facilitated as a 'think, pair, share' group discussion or writing exercise. Participants should record their thoughts about the activities and any strategies they would use to modify the activity for their own lab sessions (see Appendix A).	Provide participants with a platform to discuss both the value of these pedagogical approaches and effective examples.
30	Concept Mapping Activity	Assign groups of 4-6 participants to draw a concept map for the particular steps of the given laboratory session, incorporating the purpose of the experiment alongside the associated steps or methods as well as skills, concepts, ideas, or theories (see Appendix B). As a group, identify common misunderstandings and misconceptions that could occur in the ways that students will link ideas and organize knowledge. The facilitator should share a prepared example concept map to demonstrate the connections between the ideas and concepts. In a classroom setting, students could edit/augment the concept map over the course of the experiment. TAs could instruct the students to identify	Build student knowledge organization. Understanding how students make connections and organize knowledge is crucial to enhancing comprehension. This tool is an effective way for TAs to assess their own teaching approach and to compare their teaching 'mind-map' to how their students map knowledge. TAs can visualize and address knowledge gaps and teaching opportunities, or assess

		areas of the concept map where they might make connections to prior knowledge.	their teaching effectiveness.
20	Flowchart Summary Activity	Ask participants to complete a flowchart of the activities completed as part of the lab alongside the pedagogical approaches to help reinforce 'deep' understanding (see Appendix C). TAs can use this flowchart to conduct lesson planning or to reflect on the lab session afterward. TAs can modify this flowchart for class in order to have students record their understanding of the rationale for the lab procedures and their application. Students could arrive at the lab session with a basic flowchart outline; they would then modify and add additional details following the lab session (e.g., adding in broad summaries of each step in the experiment)	A flowchart can help a TA plan a lesson; reflect on teaching approaches and/or challenging aspects of the experiment. TAs can review student-made flowcharts to identify whether or not students achieved the lab learning outcomes. When provided, students can use flowcharts as a tool for reviewing the steps/tasks associated with the experiment, and consider the deeper meaning and application of the tasks. A summative activity like this helps students to reflect on what they have practiced and self-identify gaps in their understanding.
5	TA Reflection: Part II	Ask participants to reflect on the Concept Map and Flowchart Summary activities, and strategize ways to modify the activity or troubleshoot any anticipated issues. This could be facilitated as a 'think, pair, share' group discussion or writing exercise. Participants should record their thoughts about the activities and any strategies they would use to modify the activity for their own lab sessions (see Appendix A).	Provide participants with a platform to discuss both the value of these pedagogical approaches and effective examples.
5	Summary and Close	Summarize the learning objectives and connect the workshop activities to the objectives. Review any key	Highlight the tools provided in the workshop, and review

		ideas or adaptations that emerged in the workshop.	the importance of deep learning and understanding.

PRESENTATION STRATEGIES

When training TAs how to teach for deep understanding in laboratory sessions, select an actual undergraduate lab experiment as the basis for the training session. Depending on the selected experiment, this training session could take place in a lab setting or in a classroom. The facilitator may truncate the selected experiment for simplicity. This format will allow participants to go through the lab experiment along with its particular nuances and issues from the perspective of their students, while also exploring the utility of their own practice and implementation of the teaching tools demonstrated in this workshop. Thus, participants will acquire an understanding of how to apply the tools and to assess their effectiveness in real time. This 'simulation' approach will allow participants to consider the teaching strategies modelled by the facilitator so that they may adapt the activities to their particular needs. Provide time for participants to carry out portions of the experiment while the facilitator demonstrates the teaching tool. Participants should also have time to reflect and share their perspectives on the effectiveness of these teaching strategies.

The facilitator should explain the 'simulation' format of this workshop to the participants at the start of the training session so that it is clear that they will be playing the role of students conducting an experiment as well as deconstructing the simulation. The goal is to discuss and reflect on applying the modelled teaching tools to their own laboratory sessions. If presentation slides are used, a simple indication in the top right corner of a slide could indicate when the session is in 'demonstration mode' or 'deconstructing the demo mode'. If technology is not used, the facilitator can announce the respective sections (demo versus deconstructing the demo mode).

Prior to conducting this TA training session, the facilitator should prepare an example concept map (after Ambrose, *et al.*, 2010; see template in Appendix B). The concept map forms the teaching approach for the lab experiment and includes methods, concepts and definitions. The facilitator can provide this map to participants as an example after they have attempted to complete their own concept maps. The discussion that follows should examine the ideas related to making appropriate knowledge connections between methodology, theory, conceptual links, and application.

As part of the introductory 'lecturette' of the session, the facilitator should briefly research some applied examples related to the lab experiment that can be displayed on a projector using a single image or described as a verbal illustration to help the participants make links between what they are about to learn in the experiment and what they already know. The facilitator should base these examples on course content, popular media, historical or current events, consumer reports, popular science magazine articles, or analogies to everyday activities such as cooking or sports. In this way, the facilitator is modeling a teaching strategy for student interaction through activation of prior knowledge using applied examples. To stimulate discussion, the facilitator can employ simple prompts such as, "what parts of our experiment can we draw comparisons with in the natural world?" or "what is an interesting fact about the structure we are studying today?" However, the facilitator should also be prepared to answer these prompts in order to keep the discussion going.

ADDITIONAL REFERENCES

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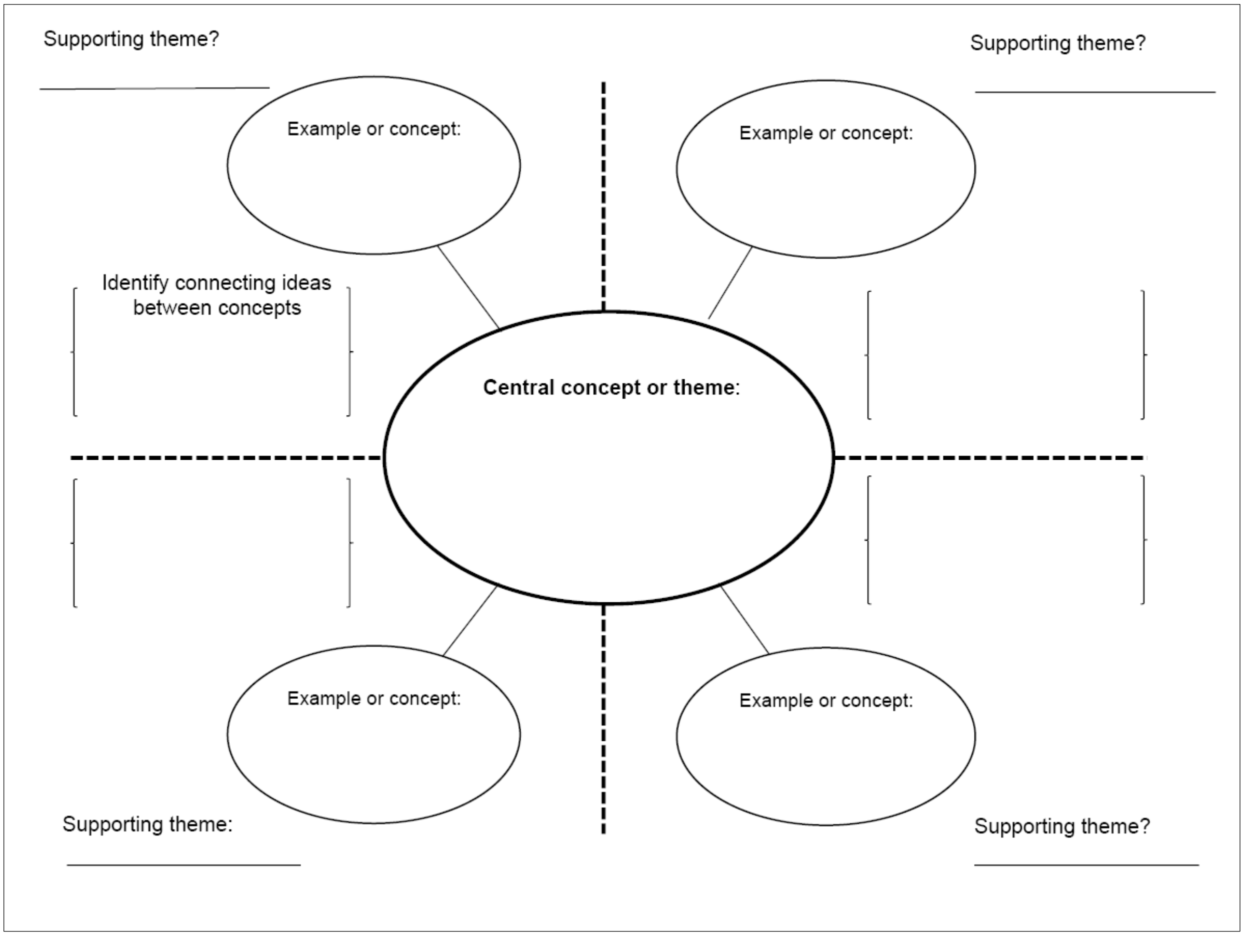
APPENDIX A: Reflection Activity Note-taking Template

Teaching Strategy	**Workshop Activity**	**Adaptation To A Lab Experiment I Will Instruct**
Self-assessment		
Applied Examples		
Concept Map		
Flowchart		
Self-reflection		

APPENDIX B: Concept Map Template



APPENDIX C: Flowchart Template