AC 2007-2062: DISTINGUISHING THE ART FROM THE SCIENCE OF TEACHING WITHIN RESEARCH-BASED CURRICULUM AND ASSESSMENT

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Distinguishing the Art from the Science of Teaching within Research-Based Curriculum Development and Assessment

Abstract

In order to create a researched-based discipline, the distinction between the art of teaching and the science of teaching must be made. Without this distinction, there can be no dialogue to objectify teaching and allow it to be critically analyzed critically, separate from the content of the subject being taught. For the past two years, the *Journal of Engineering Education* has trumpeted the need to establish engineering education as a rigorous researched-based discipline, and in the April 2006 edition of *JEE*, Ruth A. Streveler and Karl A. Smith in the guest editorial[7] described three qualities in the research questions engineering faculty tend to display as they begin to practice engineering-education research. All three qualities have a connecting thread resulting from a lack of understanding of how to distinguish between the art and the science of teaching. Clarification of this distinction will allow engineering educators to objectively see why a research study that analyzes an individual researcher's classroom practice is difficult to replicate, and why assessment of the quality of a particular teaching method is clouded so that it doesn't reach the "why" or "how" questions about engineering learning. Lack of clarification will continue allow many engineering educators to conduct context-specific studies that are difficult to replicate and have limited generalizability. Understanding the distinction between the art and the science of teaching is the framework for creating the "big picture" in the efforts to build the research-based discipline.

The purpose of this paper is to clearly distinguish the art of teaching from the science of teaching. In doing this, the paper describes the flow of using the science of learning (formed from research in cognitive psychology and cognitive science) to inform the theoretical underpinnings within the science of teaching, which, in turn, informs the art of teaching. Many engineering faculty desire to employ "active" learning methods, such as problem-centered learning or team-based projects, without an understanding of how the performance of these artistic acts of teaching must be fundamentally informed by the sciences of teaching and learning. This results in a lack of rigorous research. The goal of this paper is to distinguish between the science of learning, the science of teaching, and the art of teaching, distinctions that are necessary for continuing the paradigm shift of engineering faculty who desire to be a part of developing research-based, engineering-educational practice.

Complications in Creating Rigorous Engineering-Education Research

In the April 2006 guest editorial "Conducting Rigorous Research in Engineering Education,"[7] Ruth A. Streveler and Karl A. Smith describe three potentially problematic qualities that engineering faculty often adopt as they conduct engineering-educational research. The first of these is the faculty's tendency to create research questions that are too context specific to be generalizable and replicable. The second tendency of the research questions is they ask whether one approach is more effective than the next, and this does not answer or establish the hows and whys behind the approaches that created the conclusions. Lastly, the research questions are not well situated in prior research.

First Quality: Too Context Specific

As educators, we long to try new approaches in developing greater student learning. To this end we test the approaches in our classes, assess their success, and offer stories of encouragement, or disaster, to the next educator who desires to try the approach. I agree with Streveler and Smith that most educators enter the field of educational research through this very natural avenue of following their own interests and using their classes to test their ideas. I also agree "providing one's students with the very best teaching is admirable, …[but] the very specific nature of these studies can make their results difficult to replicate and generalize."[7] In the art of teaching section of this paper, the innumerable amount of variables in instruction that affect student learning and complicate educational research are described. In most science studies, we control all possible variables in order to test one variable. Educational research questions tested in the classroom cannot be separated from its context of variables.

For example, consider two professors who are teaching the same class during the same semester and have agreed upon the syllabus. Also assume equivalence in class size and makeup. Any differences in student engagement and learning can be partially attributed to each professor's art of teaching. If we exaggerate the differences, maybe one professor is charismatic and motivating while the other is disengaged and condescending. Whether we like it or not, common sense (and science) tells us that student engagement (and therefore potential learning) is affected by a professors' art of teaching. The reason the research questions are difficult to replicate and hard to generalize is because of the multiple variables in the professor's art of teaching.

The Art of Teaching

The art of teaching can be defined as both the conscious and unconscious decisions by an instructor that affects student engagement and learning. Curriculum is developed at the macro and the micro level. At the macro level, government policies, national policies, and university programs make some of the artful decisions affecting a course. For example, the Fundamentals of Engineering Exam can ripple into causing particular classes to be a part of degree requirements or lead to inclusion of topics in a course's content goals. On the micro level, instructors' plans are influenced by the decisions at the macro level, but they still make the choices of specific lesson plans, contents of daily/weekly/monthly instructional objectives, activities for students, methods of instruction, and forms of evaluating students.[4] In analyzing curriculum planning, Colin J. Marsh and George Willis write

> Teachers are, of course, the final planners, and, in practice, many daily lesson plans are not written out but remain in the heads of experienced teachers. In fact, many of the numerous decisions made daily by classroom teachers are the result of their long experience, not of self-conscious planning….Teachers rely on the content and methods outlined in textbooks, syllabi, and teachers' guides for their planning, but what they actually teach is a unique blend based on their own preferences. They put together their own syntheses based on their intuitive feelings and in keeping with their own artistic flairs.[4]

The art of teaching includes everything from stage presence, ability to answer student questions, choosing student activities for in class or out of class, selecting the types of questions and length

of exams, deciding the frequency of quizzes and tests, ability to communicate expectations, controlling pace of instruction, and textbook choices.

Professor personality clearly makes a difference in student engagement. Seemingly petty things like a professor's stage presence—eye contact, voice level, and body language—can make the difference of whether students bother coming to class and whether they try to learn respectfully from the professor. Steven G. Krantz may have said it best, "There is nothing more stultifying than a lecture in a reasonably large classroom on a hot day delivered by an oblivious professor mumbling to himself at the front of the room."[2] The level of respect a professor shows his students determines whether they find him approachable, and the creation of an inviting and comfortable classroom environment can greatly influence students feel they are able to be successful. But the professor is only one source of variables in the classroom experience; the students are another. "Indeed, there is a wealth of research that focuses on motivational characteristics such as perceptions of ability, intrinsic motivation, valuing of academic tasks, and perceptions of belonging, that has shown that [student] motivation can directly impact achievement and achievement-related cognitive variables."[8] These variables in students' motivation and professors' art are intricately tied to student learning outcomes; thus, if research projects were created to test the learning outcomes of these classes, the assessments of student learning would be a result of a combined influence of several variables within the context of the classroom. An argument for a causal relationship between a new approach and the success rate is impossible because the results are caused by the interrelationships of several variables. The research question may be too limited to answer what variables actually caused the results.

As an example, assume a professor tried a new approach in her classroom, observed an increase in student engagement, and assessed an increase in learning as compared to the learning she observed from the last six semesters. So, did the new approach work? Did the approach work because the students were motivated to engage? Engagement almost always produces learning. Did that engagement come from the new approach or just a motivational talk by the professor? Then, the learning may not be a result of the new approach but a result of a motivational talk by the professor. That makes the study non-generalizable, unless we can study her motivational speech in order to objectify what aspects caused the engagement. These magic words could then be used to cast a spell on all students everywhere, causing student engagement to increase beyond measure all across the land! In reality, all motivational teachers know that sometimes a motivational talk works, and sometimes it does not. Even the most charismatic professors know that their personalities cannot guarantee student learning; students must make sense of the material for themselves.

Art of Teaching: A Thick Layer of Variables to See Past in Research

Because of human personalities and instructors' freedom in their art of teaching, any research done inside a classroom is too context specific to be generalizable. Every artful choice of the instructor is a variable affecting the classroom environment and student learning, which is why it is difficult to create causal relationships in classroom environments. What actually caused the approach to work, or not to work, in the above example can be caused by several variables.

It may not have been the motivational speech; instead, it may have been that the instructor spent a lot of time thinking through the new approach, aligned the tests better than usual, had a more reasonable pace of instruction, or spent a lot more time interacting with the students and answering their questions. All of these variables are changes in art of teaching that may have caused the approach to work. Likewise, since the approach was new, maybe the tests were not as aligned, wording of the activities was poor and student fumbled to understand, or the pace of instruction was too fast. In either case, a research study would give faulty results to the research community because the results would not be guaranteed to be replicable and generalizable. Currently educational researchers live in the time in history where educational researchers are trying to objectify what aspects of an approach enhance learning. The question research needs to address is "What variables can and must be controlled to guarantee success in any classroom with any professor and any group of students?"

2nd & 3rd Qualities: Comparing Methods and Lack of Literature Foundation

Factors that enhance (or impede) student success are often hidden among numerous other variables; thus, the results of many educational studies are too context-specific and are difficult to replicate and generalize. This is the cause for the conflict in the second and third qualities mentioned by Streveler and Smith. The second quality described was that the research questions "tended to focus on assessment questions that would help ascertain if one teaching method had a more positive impact on student learning than another."[7] The third was that the questions "were often not linked to learning, social, psychological or pedagogical theory."[7]

When faculty read papers and attend workshops that offer advice toward improved teaching methods, it is natural to want to create an objective research project to compare assessments; however, there are too many variables affecting student learning to objectively say whether a certain teaching method was the cause of the gain/loss of learning.

As an example, numerous papers across many engineering websites recommend group projects as an approach for instruction for student learning gains over traditional lectures and homework sets; however, numerous professors and students would argue the contrary. Why the difference? Maybe it results from the group projects' being disconnected from the instruction available through the textbook and the students' not having the support to complete the project well. Or maybe the students are floundering because of team dynamics. Yet another possibility is the project is designed such that it is best suited to be a one-person job; thus, only one person does the work and all the other students are forced to loaf (or lazily accept). Unless group projects are engaging all students in brainstorming the project, independent homework sets that force each student to wrestle with the material may create larger learning gains. So an engineering-educational researcher is wise to ask, "what are the needed variables (in development, in student support, in team dynamics…) in order to guarantee a group project will facilitate all students to wrestle with the material and guarantee learning?"

Some professors may argue, "Why bother with doing all this talk of reform if strategies like the group projects are not always more effective than traditional lecture and individualized homework?" This question is quite reasonable and should be asked because it underscores the need for scientific rigor in educational research. The question also emphasizes the importance of

a strong theoretical foundation for all research based upon our best understandings of learning, social, psychological, and pedagogical principles.

How *do* people learn? Knowing how people learn can explain why lecture and "drill-and-kill" homework sets can be effective in helping students learn content knowledge and, at the same time, explain why inductive teaching methods, such as project-based instruction, guided inquiry, discovery learning, and just-in-time teaching, are recommended as "better" approaches. It is like using a nail gun as a traditional hammer. Without the electricity, it would be more cumbersome to beat a nail into a wall with the nail gun's handle than it would be to use the traditional hammer. There are physical laws and principles of design that make a traditional hammer more effective under certain conditions. Science principles of leverage and force were applied to create the shape of the hammer in order to minimize human effort and to maximize effective results. However, the nail gun uses electricity to be even more effective by minimizing human effort and maximizing effective results. Without the electricity, the traditional hammer is more effective. With the electricity, the nail gun is usually even more effective. Similarly, lecture and drill-and-kill homework sets are effective for allowing students to learn and are probably more effective than potentially better techniques that are misapplied. But if the appropriate learning research is applied to these newer techniques, they can maximize student learning and minimize cumbersome human efforts.

Lecture and drill-and-kill homework sets are effective for allowing students to learn because they were founded on traditional ideas about learning based in behaviorist psychology, a theory of learning that dominated educational thought in the U.S. for nearly a century. However, newly developed teaching strategies can enhance student because these techniques apply principles of learning based in cognitive science, which provides a modern, scientific understanding of human learning that is much more comprehensive than behaviorism. New teaching strategies are not thought to better simply because they are new but because they are based on research that provides a better understanding of the way humans learn.

Toward Resolving the Complications in Creating Rigorous Research

Because of all the variables that can complicate a question of whether a method is effective or not, it becomes the wrong question for research studies to advance any field of education. Both researcher and curriculum developer could advance the field if they began with the question, "What are the essential properties that all people use/have when learning?" and then asked "What overarching characteristics would employ these human properties of learning?"

Many fields of study have been studying how people learn and trying to discover overarching characteristics that would effectively employ the nature of the learning mind and the learner in a social context. How people learn is generally studied by the cognitive and psychological sciences. This is the science of learning. How to effectively employ the nature of the learning mind is cutting across all fields of educational study, and this is the science of teaching.

Because professors are offered a bubble of autonomy within their classes, the manner by which each professor decides, and for what reasons he decides, are based upon his values. Sometimes decisions are unconscious or taken-for-granted based upon current American culture. Other times the decisions are imposed by constraints from the academic community. The goal of educational research is to provide faculty principles of learning in order that the art of teaching is less arbitrary and more informed. To have the greatest generalizability, the goal of research must be to identify factors (e.g., teaching practices, curricula, environmental conditions, etc.) that enhance learning in any classroom with any professor and any group of students.

In the past fifty years, these principles have become less philosophical and more a product of multidisciplinary science. The research seeks to answer the questions of how people think, learn, and develop both as individuals and as members of communities. However, each individual research report contributing knowledge to the science of learning is too specific to benefit educational practitioners. For example, the article "Differences among Teachers in a Task Characterized by Simultaneity, Multidimensionality, and Immediacy" in the American Educational Research Journal had expert, beginning, and novice teachers view "three television monitors, each focusing on a work group of a junior high science class, simultaneously."[6] Individuals were then asked questions about classroom management and instruction based on what each viewed. The findings showed that expert teachers showed incredible depth and perception concerning classroom management and instruction while the beginning and novice teachers were only aware of surface features. The authors hope that the findings have implications for the development of pre-service and in-service training programs.

This research project, in and of itself, has very little application for creating and assessing engineering curriculums, but taken as one piece in the countless research across dozens of disciplines in the past fifty years, it shows "the idea that experts recognize features and patterns that are not noticed by novices."[3] This idea of what novices are *able* to be conscious has huge implications for educational practitioners, and it is a central philosophy from the science of learning for the science of teaching.

However, for engineering faculty to be expected to sit down and read the volumes of research in cognitive science, psychology, anthropology, linguistics, philosophy, and neuroscience is impossible. It is necessary to benefit from people who are in a position in their expertise to synthesize the overarching theories, themes, and results to be used in our classes. One example of such a text was created by the National Research Council in their report *How People Learn*. In the first chapter, they give a brief history of the science of learning and report three chosen key findings concerning learning and learners backed by "a solid research base to support them and strong implications for how we teach."[3]

A Quick History of the Science of Learning

How People Learn explains that having its original roots in the studies of philosophy and theology, the science of learning began being shaped by systematic, scientific methods in the latter part of the nineteenth century when researchers asked subjects to reflect and report on their own cognition. At the turn of the nineteenth century, using such subjective data for analysis was abandoned in favor of using only observable actions as appropriate objective data. This resulted

in the behaviorist perspective, where learning is understood as the formation, strengthening, and adjustment of associations between ideas, stimuli, and responses. These theories "are framed by the assumption that behavior is to be understood as the responses of an organism to stimuli in the situation,"[1] which usually can be defined as rewards or punishments for the individual. With a theoretical paradigm that only allows for observable actions to be taken as data, theories concerning reasoning, understanding, problem solving, and thinking that occur within an individual were nearly impossible to test.

However, with the boom in technology and the advancement of rigorous qualitative research methodologies, the last fifty years have seen the birth of cognitive science to describe learning and understanding and research explaining the effects of social and cultural contexts. This has resulted in the cognitive perspective and situative perspective. The cognitive perspective "on knowledge emphasizes understanding of concepts and…general cognitive abilities, such as reasoning, planning, solving problems, and comprehending language"[1];whereas, the situative perspective "views knowledge as distributed among people and their environments, including objects, artifacts, tools, books, and the communities of which they are apart."[1] It is the convergence of overarching themes in the multidisciplinary and multiperspective study of learning that has resulted in the science of learning.

The Themes in the Science of Learning

The first of the three key findings mentioned in *How People Learn* is that students come to formal educational experiences with preexisting knowledge, skills, and beliefs that will shape their new learning. This preexisting knowledge may be accurate or inaccurate in its ability to converge on the true state of affairs. If their knowledge and beliefs are accurate, it can serve as a powerful foundation for further learning because it adds depth of experience. However, if inaccurate, students may learn class content for a test and then revert back to their initial beliefs in later experiences. *How People Learn* states, "Numerous research experiments demonstrate the persistence of preexisting understandings among older students even after a new model has been taught that contradicts the naïve understandings."[3] Other research shows it is possible for people to have contradicting beliefs simultaneously and not realize it. Thus, unless the two beliefs are simultaneously activated, they may coexist without being clarified. It is necessary for the student to be forced to activate both thoughts and be able to work through the cognitive dissonance. Otherwise, students will either revert back to a preexisting belief or be unable to appropriately apply knowledge consistently. It is understandable that with inaccurate beliefs and knowledge as a preexisting lens, all further instruction will be twisted and misinterpreted.

Secondly, for students to progress from novice to expert in a field of study, they must gain factual knowledge, but factual knowledge is not enough to create understanding within the field. Students must organize knowledge within their own minds, connect it to preexisting knowledge, and strengthen connections between interrelated concepts. This is different from when a professor tells students what are common misconceptions or emphasizes the relationships because, in and of itself, a statement by a professor concerning misconceptions or relationships is received by students as factual knowledge. It is only when the student is able to work through and fix a misconception or when the student identifies a new relationship that deep understanding is made possible.

Deep understanding is a result of a conceptual framework being developed, a type of internal web created by the connection between interrelated topics, skills, and ideas. "Deep understanding of subject matter transforms factual knowledge into usable knowledge. A pronounced difference between experts and novices is that experts' command of concepts shapes their understanding of new information: it allows them to see patterns, relationships, or discrepancies that are not apparent to novices."[3] Thus, learning, memory, and application of new knowledge are made possible by flexible, adaptive thinking. Instruction that gives great breadth of content without allowing students to simultaneously build depth and complexity of understanding will result in poor memory and weak transfer to novel problems.

Of course, if understanding is the goal, then students must become powerful metacognitive thinkers. Metacognition can be defined as the thinking about ones' thinking. As students think through a problem, they must be able to reflect about what their reasonings are in order to monitor and assess what they do or do not understand, what information is missing, and whether new information is consistent to their current understanding. Metacognition is a type of internal dialogue that must be practiced, much like many other skills.

Another important theme, though not emphasized in *How People Learn* is engagement. Student cognitive engagement includes topics concerning their intrinsic and extrinsic motivation, identification with academics, and self-efficacy. Common sense says if students want to learn, feel they can learn, and feel that others believe they can learn, then they will be more successful than those who do not. A great article to be used as a spring board for research studies in regard to these topics is "Identification with academics, intrinsic/extrinsic motivation, and self-efficacy as predictors of cognitive engagement."[8] According to its literature review, students with intrinsic motivation achieve better academically than those with extrinsic motivation, students' future academic outcomes are related to their level of identification with their academic domain, and students' confidence in their ability to succeed academically, known as self-efficacy, is related to their ability to think metacognitively which translates into higher academic performances.

These four themes within the science of learning have implications for teaching, and those direct implications can be classified as the science of teaching. Harvesting the themes within the science of learning directly informs the science of teaching. It creates a list of necessary principles that must be included as we develop our instruction and classroom environment within the freedoms of the art of teaching.

The Principles of the Science of Teaching

If students come into our classes with preconceptions about how the world works, then the first principle must be that student preconceptions must be drawn upon to integrate new concepts. If students come with inaccurate preconceptions, those beliefs must be brought to their conscious thoughts simultaneously with the contradicting concepts. Creating cognitive dissonance and allowing students to resolve it is necessary so that inaccurate understandings can be replaced or adjusted. A central tenet for Piaget's research was the need for cognitive dissonance to advance learning. Cognitive dissonance causes students to organize their thoughts,

justify their decisions, and seek resolution. In this way, cognitive dissonance is a central tenet for learning. When students seek resolution, they are being intrinsically motivated. When they are forced to justify their decisions, they continue to retrieve, develop, and apply a deep foundation of factual knowledge. When they have to organize their thoughts to seek resolution or to justify their resolution, they are extending and developing their conceptual-framework web. All the while, they must practice their skills of metacognition to figure out why they believe what they believe and what can be done to resolve the conflict. Thus, creating experiences where students undergo cognitive dissonance causes all three of the first themes from the science of learning to be employed. The fourth theme, concerning engagement, requires that students feel they are able to resolve the conflict or they may become disengaged. Again, according to Walker, Greene, and Mansell's article, "Research has demonstrated that students with high self-efficacy are more likely to seek challenges, persist in the face of those challenges, and adopt effective strategies to mediate those challenges when compared to their classmates with low self-efficacy."[8]

Instead, if students come with accurate preconceptions, they must be employed so they can serve as a foundation for integrating the new relevant information. Of course, there is no way to know which students will have accurate or inaccurate preconceptions. Thus, when instruction lends itself to problem solving, students become situated so that they must begin with what they know (or their initial hunches) and actively think and integrate new content with their preconceptions. Problem solving means students are actively thinking and developing/monitoring their conceptual framework for possible leads. It is not about working a problem to a solution; problem solving is the very vehicle that students practice the process of engineering. Developing and practicing the skills of metacognition are necessary for figuring out what they do know, what progress they have made in resolving the problem, and the necessary knowledge and procedures needed to test their ideas, adapt their thinking, or apply knowledge to new situations. Problem solving usually causes cognitive dissonance, which means all the positive attributes from the science of learning for which cognitive dissonance allows, are also employed by problem solving.

Cognitive dissonance and problem solving create consciousness; thus, consciousness is the central tenet of the science of teaching. Are your students conscious of their preconceptions? Are they conscious of how their preconceptions and hunches work to support or contradict instructional content? What are the students becoming conscious of as they come to class or as they complete out of class assignments? Are the students conscious of what they need to know and what they need to do to solve a problem? Are they conscious of their attitudes or beliefs that hinder their academic progress? All elements within the art of teaching must be informed by the principles of the science of teaching.

Influencing Art of Teaching: Behavioristic vs. Cognitive Models

Currently, our culture allows the behavioristic model to influence the art of our teaching. Most traditional engineering courses involve the students being assigned textbook readings, reintroduced to the material through lecture, assigned homework and/or labs to reinforce the learning and processes, and given quizzes to provide feedback and to provide clear goals for instructional ends. This pattern is established by the lens of behaviorism that posits that learning

must be segmented into learnable chunks that develop in complexity as initial learning is accomplished. Chunks of learning need to start small, and all small parts must be individually established before they can be applied and strung together. Behaviorism holds that practice, reinforcement, and feedback are key elements to learning.

This is different from the cognitive view of learning, which proposes that learning environments should be interactive "to foster students' constructing understanding of concepts and principles through problem solving and reasoning in activities that engage students' interests and use of their initial understandings and their general reasoning and problem-solving abilities."[1] The cognitive view of learning does not believe that learning should be segmented into accessible chunks by the teacher, but instead it should proceed from problems that are appropriate for students' level of reasoning. Learning is messy, and the way forward is sometimes the way back while problem solving. The cognitive view claims that for students to create their own conceptual framework of understanding and to create relevance for learning, teachers must guide students to construct, monitor, and organize their own knowledge.

Thus, when a professor begins to organize the course, the leading question must be "How am I to create consciousness of my subject area such that my students engage their preexisting knowledge/hunches and actively learn by problem solving?" Maybe, much like the behavioristic model, having students read their text before class is the chosen first step in creating consciousness. This is fine, but what happens next will be different from the behavior model. Behaviorism will seek to reinforce the reading by hearing a lecture on the topics, doing a lab to show the topics, or give a quiz to provide feedback. Realize, reading a chapter creates shallow breadth of knowledge. In order for students to weave depth of understanding, cognitive dissonance and problem solving must be the next step in instruction in the cognitive model so that students are monitoring what they do and do not know, so they are organizing what they do know and connecting relationships between ideas, and constructing continued depth of knowledge. What does that look like as a student activity? It can be an interactive lecture, a lab project, or a quiz. Surprised?

According to surface features, the list may seem equivalent to the behavioristic model, but it is the themes of the science of learning and the principles of the science of teaching that must inform the art of this choice. If the lecture is chosen in a behavioristic model, students spend the majority of the class time hearing the material reinforced. Some questions may be allowed, but, overall, they are being recipients of the knowledge again. In a cognitive model, class time would be spent having instructors draw out and work with the preexisting understandings that the students have now brought to class.[3] Instructors interact with the students in such a way that the students are forced to monitor what they know, continue to organize connections, and construct further depth of understanding. The students do most of the talking and thinking and stay actively engaged in furthering and reworking their understanding.

Of course, it is difficult for an instructor to interact actively with each student; therefore, in an attempt to employ active learning, the sciences of learning and teaching ripple into affecting the choices in the art of teaching. If students need to be thinking for themselves and actively engaged, and yet it is impossible for the instructor to keep every student engaged, a need to adjust their art of teaching where instructors choose to pose questions or problems to the

students and allow them to work in pairs, small groups, and larger groups becomes necessary to keep all students actively engaged and developing their understanding.

The magic is not in the group work. Group work is just an artistic choice of approach that allows students to construct, monitor, and organize their thinking actively during class. Further construction and the need to monitor and organize their understanding are possible if dissonance and problem solving instigate further consciousness and thinking. Problem solving engages preexisting understandings, and along with it dissonance allows students to compare and relate contrasting content knowledge. In working together, students monitor and express what they do and don't know. Thus, they receive feedback from their peers. This feedback will either create further connections of ideas or will create dissonance. It is a cycle where learning occurs.

Of course, the singular artistic choice of using group work is not enough to guarantee that dissonance and problem solving will occur for all students. There are more artistic choices that will cause variation in the effectiveness of the group work. One such variable is that the problem posed by the instructor, and these problems could be short conversations, problems to be calculated, or lengthy case studies, could not be effective for creating an experience where students will interconnect ideas and have to monitor their thinking in order to develop construct and organize their knowledge further. Maybe the question is too easy; maybe it is too far out of reach. It may also be that the question was too poorly worded. All of these variables are variances in the application of creating problem solving and dissonance. It is not that the group work can be researched as ineffective; it is that the questions must be reworked until student learning can best be achieved. Just as a lecture is reworked each year by an experienced instructor based on students misconceptions, so also must group projects be reworked until the variable of poor application does not interfere with the variable of choosing groups to employ the science of learning.

Another variable to consider in the art of teaching of choosing to employ groups is social dynamics. Each of us has been trained by our culture, directly or indirectly, how to speak and adjust our discourse to people in authority, close friends, and during speeches. Students must be trained to learn how to communicate in pairs, groups, and large classroom dialogues. Secondly, it is also important that an instructor allow students to engage alone and then combine with a partner or team to work to resolution. If students are just put within a team immediately, they may follow a particular student's leadership and not engage their own beliefs. Thus, one of the principles of learning, engaging preexisting beliefs, is eliminated. On the other hand, if students are left exclusively as individuals to solve the problem, they may not become conscious of the smallest item that is causing confusion or error. Putting students into pairs or teams increases their consciousness of possible solution paths, but if the pairs or teams allow for students to become couch potatoes, consciousness is once again lost.

Research: How the Art of Teaching Gets in the Way

That is why research projects on whether or not team projects increase student achievement may be misleading. The question is too narrow for the multiple variables affecting the outcome. In the art, there are several variables for which researchers must account in order that they might employ the principles of the science of learning fully. What happens if the team

projects allowed students to divide and conquer—thus causing each student to be conscious of very little of the entire learning needed to complete the project? What happens instead if team projects cause students to problem solve, actively learn, and resolve cognitive dissonance? Because the latter type of projects employs the principles from the science of learning, it will have greater student achievement (unless some other aspect of the instructor's art became a detriment to student learning).

But these complications with the art of teaching do not just affect team projects. It affects all approaches. Consider case studies. People have done research studies whether case studies are effective for greater student achievement. Here again, the results will depend on whether the art of using case studies was informed by the sciences of learning and teaching—or not. Are the case studies used as a means to practice and reinforce learning? Or are they used as a means of causing cognitive dissonance and practicing problem solving? If students are taught a unit of content and then asked to practice their learning with a case study, students' learning will be reinforced through the practice, and they will, most probably, need to reread and spend time furthering their understanding to complete the problem. Case studies used within a behavioristic model do create learning. However, case studies used within a cognitive model will be given near the beginning of the unit of study even though students do not have the knowledge yet to solve it. Despite their lack of learning, they are asked to begin to solve it. As students work through the problem, they begin to monitor and analyze what content knowledge is necessary for them to progress to a solution. This analysis causes class readings to be seen as relevant and helps students organize their cognitive framework. Depth of learning is developed along with breadth of learning.

One of the goals of current curriculum reform is to ask what conditions in the art of teaching are necessary to satisfy proper alignment with the sciences of learning and teaching. When instructors create their syllabi, they must decide how they desire to organize experiences for the students that facilitate consciousness, engage preconceptions, create cognitive dissonance, cultivate a deep foundation of factual knowledge, and enrich the understanding, retrieval, application, and transfer of such content knowledge. This can be done with a number of different types of arts: case studies, team projects, the just-in-time instructional loop, and problem-based learning techniques. The content of the course usually affects the necessary choice of approach.

The problem with doing research projects on curriculum effectiveness is the complicated dimension caused by the art of teaching and the personalities of the students. Were poor scores for student assessment a result of poor teaching techniques—or ineffective use of them? What effect did the culture of the classroom tone have on student learning? What effect did instructor personality? Are poor scores caused by students spending too much time on another class and did not invest in yours? Did the students feel supported or stranded during their cognitive dissonance? Did they feel they could accomplish goals—and that goals were worth while? How do we know whether it was the team project or the personality of the professor that caused students engagement?

It is these types of questions that led Ruth A. Streveler and Karl A. Smith in their guest editorial in *Journal of Engineering Education* article to state, "the very specific nature of these

studies can make their results difficult to replicate and generalize."[7] They go on to say research assessments that seek to "ascertain if one teaching method had a more positive impact on student learning than another … cannot help answer the "why" or "how" questions about engineering learning that the engineering education community is now being asked to answer. That is not to say that research assessment of this type must be completely abandoned. These research projects can be used as case studies that serve as

> instructional models about conditions that need to be satisfied for reforms of the same kind to be successful, and about conditions that impede success. Results also contribute to an accumulating body of theoretical principles about processes of cognition and learning in the social and material environments of schools and other settings.[1]

However, as faculty create such research projects, there is a necessity of stratifying all the elements of the classroom and attempting to allow the science of learning to inform every aspect of the art of teaching. Research projects must also frame their questions and data collections to reach beyond the surface levels in the art of teaching to offer specific answers for other engineering faculty of which conditions must be satisfied in the art of teaching to allow the science of learning to be employed.

Research questions and curriculum development are strengthened by understanding that the art of teaching must come from an understanding of the sciences of learning and teaching. Multidisciplinary research shows that learners come with preexisting knowledge, skills and beliefs that affect their continued learning. It also shows that learners must develop their own web of connections and deep understanding. This is made possible by their developing their metacognition and by their being actively engaged. The science of teaching has established that all four of the themes in the science of learning can be accomplished by creating situations causing cognitive dissonance, furthered consciousness, and a need for problem solving. If every aspect of a professor's art of teaching is aligned with employing the sciences of learning and teaching, learning can be maximized.

All the possible variables in the art of teaching destroy the ability to replicate and generalize most research studies. Knowing this allows faculty to read existing research with a careful eye of skepticism. There are many articles in the *Journal of Engineering Education* referencing research projects attempting to answer whether active learning techniques are effective. The magic is not in the use of the technique but rather all learning is made possible by the learner making sense of the content for themselves. The techniques, if successfully employing the theories and research from the sciences of learning and teaching, are just tools to help facilitate greater student learning. The traditional manner by which we teach with lecture and individualized homework sets is largely a cultural artifact of when behaviorism was the leading philosophy explaining how people learn. Today, the boom in technology has caused a boom in research where learning can better be described within a cognitive model.

The article "Does Active Learning Work? A Review of the Research" in July 2004 of *JEE* by Michael Prince closely parallels the claims of this paper. In the third section of his article, he describes common problems interpreting the literature on active learning, all of which are caused by the art of teaching. Knowing that the multitude of variables within the art of teaching can affect the effectiveness of a technique explains why he "found that there is broad but uneven support for the core elements of active, collaborative, cooperative and problem-based

learning."[5] Again, it is not about the technique, it is about understanding the theories from the sciences of learning and teaching that will allow the technique to be powerful. Engineering educators could greatly help each other by discovering the overarching characteristics that can guide instructors in their artful choices of implementing these new methods.

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