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# A Guidebook On Conceptual Frameworks For Research In Engineering Education

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# A guidebook on conceptual frameworks for research in engineering education

## Introduction

Why should you care about the conceptual frameworks that underlie research on teaching and learning? I propose that you wouldn't consider redesigning a bridge without understanding the underlying principles that support and affect it in the first place. Wouldn't you look to current models of mechanics, materials science, civil engineering, geology, maybe even climatology to inform your questions about its form and function? Those specialties would help you understand the kinds of data to gather, the questions to ask, the variables to consider. They would save you time and effort by focusing your attention on key components that your new design should investigate. They would help you interpret the data you collect and make decisions about what to do at each stage of the process.

The same is true for redesigning educational systems. The underlying models for education come from psychology, sociology, communications, and other behavioral sciences. Just as models from the disciplines listed in the previous paragraph would in engineering, the models in the fields in this paragraph will help researchers in engineering education to save time and effort and to ask reasonable questions informed by what is known about the influences on human learning.

## What is a conceptual framework?

A conceptual framework is an interconnected set of ideas (theories) about how a particular phenomenon functions or is related to its parts. The framework serves as the basis for understanding the causal or correlational patterns of interconnections across events, ideas, observations, concepts, knowledge, interpretations and other components of experience. Everyone has a conceptual framework about how reality works that allows him or her to make predictions about how A is related to B and what will happen when the two intersect. This allows us to make choices about our behavior on the basis of what we think those relationships are. For example, if I operate according to a conceptual framework like gravity, I will predict that a ball will drop if I let go of it. I don't know every detail and underlying construct related to gravity, but I have enough experiences in real life to form a framework about physical events that happens to be consistent with those of Newtonian physics, a much more complex conceptual framework than mine.

Conceptual frameworks influence how we interpret events, too. For example, for many decades the Copernican conceptual framework of the universe caused astronomers to explain celestial phenomena in very complex ways. Everyone agreed that this must be what was happening in the universe since their observations were consistent with that model. Then Galileo proposed a simpler model to explain all the same observations and possibly some that the Copernican framework couldn't without standing on its head. The new heliocentric conceptual framework made things much more straightforward and eventually its powers of explanation and prediction led to its adoption by most astronomers, if not the church's hierarchy.

In the same way, your conceptual framework about how learning or motivation work influences how you interpret what happens in your classroom and what kinds of cause and effect relationships you think might be responsible. Those interpretations then influence what kinds of questions you might ask in an educational research or instructional setting. For example, if your learning framework held that learning occurs by constantly repeating a pairing of a stimulus and a learner response, then you would design research to ask such questions as "how many pairings does a student have to experience for the learning to hold up over the long term?" or "are there some stimulus/response pairings that are more effective than others?" Indeed this was the type of research that was done in education during the 60's when behaviorism was the dominant conceptual framework. Similarly, the instructional designs that came out of behaviorism depended upon the pairing of stimuli and student responses with appropriate reinforcement over a long period of time. The use of drill and practice methods would be consistent with the idea that learning requires multiple pairings.

Just as Galileo's revision of the astronomical conceptual framework changed a lot of observational practices and interpretations of celestial phenomena in its day, revisions to learning and motivation frameworks are impacting the type of research and instructional design used in education today. Today's dominant learning and motivation theories are based on learners' thinking and interpretation of the situations in which they find themselves. This conceptual framework change has led to a lot of changes in the way psychologists do research in education and in the ways that instruction is designed. Today's research questions revolve around how new information is interpreted by learners and incorporated into their world view. In terms of practice the students are more likely to be involved in controlling their own learning because we believe that learning is a reconstruction of world views by the learner, not just a set of stimulus/response bonds imposed by repetition in the environment.

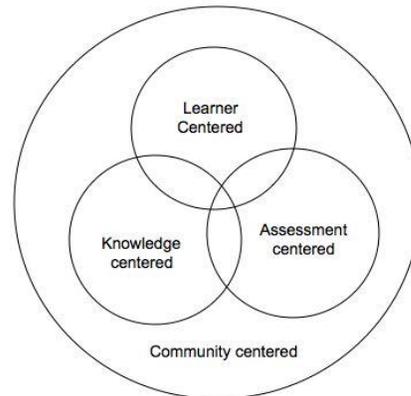
### A modern framework for instructional design

One very well-known meta-framework for instructional design is presented in the How People Learn (HPL) model described by Bransford, Brown, and Cocking (1999) and published by the National Academy of Sciences. This model (shown in **Figure 1**) combines the four most common thrusts of work on instructional design. These theorists have combined a great synthesis of work in educational research and identified the four areas that instruction should include to maximize learning.

According to this paradigm, instruction should be:

1. Student-centered – driven by the knowledge, skills, attitudes and needs of the learner.
2. Knowledge-centered – focused on helping learners develop a deep understanding of the content and processes of the discipline.
3. Assessment-centered – keyed to both formative and summative evaluation with frequent and informative feedback and revision.
4. Community-centered – based in a community of learners within the learning situation and connected to the community at large.

Figure 1: How People Learn Framework



Behind the HPL model are some very well researched areas of learning and motivation, which can form the basis of your own research on how and why students learn engineering. These areas include theories about learning itself, about the learners and the contributions they bring to the situation developmentally and motivationally, and about the contexts in which learning occurs and how they affect the process. The purpose of this handbook is to link researchers' questions to the kinds of background concepts and literature that will help inform study designs, the kinds of data that would be useful to collect, and the ways to interpret the results.

### What's in this guidebook?

What follows in the sections of this guidebook is a series of question clusters about education that a group of engineering educators generated at a retreat in August of 2007 organized around the HPL meta-framework. Each set of questions is used to represent the kinds of theoretical frameworks that might be appropriate to consider in searching for an answer. The framework descriptions are not exhaustive, but they are well-grounded in educational theory as it stands today. Each section includes the description of the predominant theories along with a summary of what the theories in that area mean for your own research and instructional design.

Following the descriptions of the theories is a section on how those theories get used to answer research questions. As an example, I take one scenario (a bimodal distribution of grades in a class) and analyze how it might be studied using different theories. That section of the guidebook is used as an illustration of the research process: moving from behavioral observations to research

questions ("My students are having this problem. I want to know why.") Or moving from theories to research questions ("Theory says that having choices should increase motivation. Does it?"). Either way is found in the educational research literature.

The descriptions of the theories are accompanied by references to secondary sources that can give you a more complete picture of how the theory explains learning. The meta-framework of HPL can be found in the NAS book How People Learn: Brain, Mind, Experience, and School (Bransford, Brown and Cocking, 1999). In general, you might also consider getting a basic educational psychology textbook like Ormrod's Human Learning or Schunk's Learning Theories: An Educational Perspective to serve as a guide (almost any one will do; they're pretty much all alike). If you want to get a lot more sophisticated, I would recommend tackling the various editions of the Handbook of Educational Psychology (published every ten years and filled with comprehensive articles about the key areas of educational research) or the Annual Review of Psychology (published every year with topics repeating about every three to five years and filled with articles that summarize and critique the literature up to that date). These are graduate level reading but always very up-to-date on where the field stands at this point. At the end of each section, I also include some other sources that aren't specifically mentioned in the text, but which I consider to be useful.

Another source not quite so complicated but equally informative is Learning and Motivation in the Postsecondary Classroom, (Svinicki, 2004) which was written with college level faculty in mind. I refer to this source specifically in the text where appropriate not because it is the most complete explanation of all the ideas presented here (or to sell more books), but because it was intended for this audience, and I think provides a good foundation. I will point to specific chapters in the book as appropriate.

Some other very basic but important references and databases are listed below. (I am indebted to Ms. Janelle Hedstrom, Educational Librarian at the University of Texas Perry Casteneda Library for these excellent references on educational theory and research.)

#### General reference sources

- Gale Virtual Reference Library – Encyclopedia articles from all disciplines
- Health & Psychosocial Instruments (HaPI) – Find test and measures printed in books and articles.
- Mental Measurements Yearbook – Reviews and provides details about tests and measurements
- Oxford Reference Online – Definitions and brief encyclopedia articles

#### Psychology reference sources

- Elsevier's Dictionary of Psychological Theories
- Encyclopedia of Cognitive Science
- Learning & Memory
- Learning Theories A to Z

#### Online databases associated with educational research

- ERIC (1966 – present) –Indexes 560 education journals and thousands of documents
- Academic Search Premier – Large interdisciplinary database

PsycINFO (1887 – present) – Most comprehensive psychology database.

Web of Science – Searches through influential journals in science, social science and the arts.

Allows citation tracking for some major education journals: “how many times was this cited and by whom?”

## Readings

Annual Reviews of Psychology (various years) Stanford, CA: HighWire Press.

Alexander, P., and Winne, P. (Eds.) (2006) Handbook of Educational Psychology. 2<sup>nd</sup> edition. Mahwah, NJ: Lawrence Erlbaum Publishers.

Berliner, D. and Calfee, R. (Eds.) (1996) Handbook of Educational Psychology. New York: Simon & Schuster MacMillan.

Bransford, J., Brown, A. and Cocking, R. (1999) How People Learn: Brain, Mind, Experience, and School. Washington, DC: National Academies Press.

Fink, D. (2003) Creating Significant Learning Experiences. San Francisco: Jossey-Bass Publishers.

Ormrod, J. (2008, 5<sup>th</sup> edition) Human Learning. Upper Saddle River, NJ: Pearson Prentice Hall. (This is an undergraduate textbook I use.)

Svinicki, M.D. (2004) Learning and Motivation in the Postsecondary Classroom. San Francisco: Jossey-Bass Publishers.

## A Compendium of Theories That Inform Educational Research

### Section 1: Theories about learning – part of the learner-centered framework

A large part of educational research is focused on how to improve learning. In order to study this phenomenon, we look to theories on learning such as those illustrated in Figure 2 (The concept map on theories of learning). We can see that there are two major divisions of learning theories in vogue right now: Cognitive theory, which is best for learning facts and principles; and Social Cognitive theory, which is best for learning skills and procedures (including intellectual skills like critical thinking). There are three versions of cognitive theory and two of social cognitive theory. Each of these theories is explained in more detail below along with some examples of how they might inform research and instructional design.

#### 1A. Theories on learning content (Svinicki chapters 2 and 3)

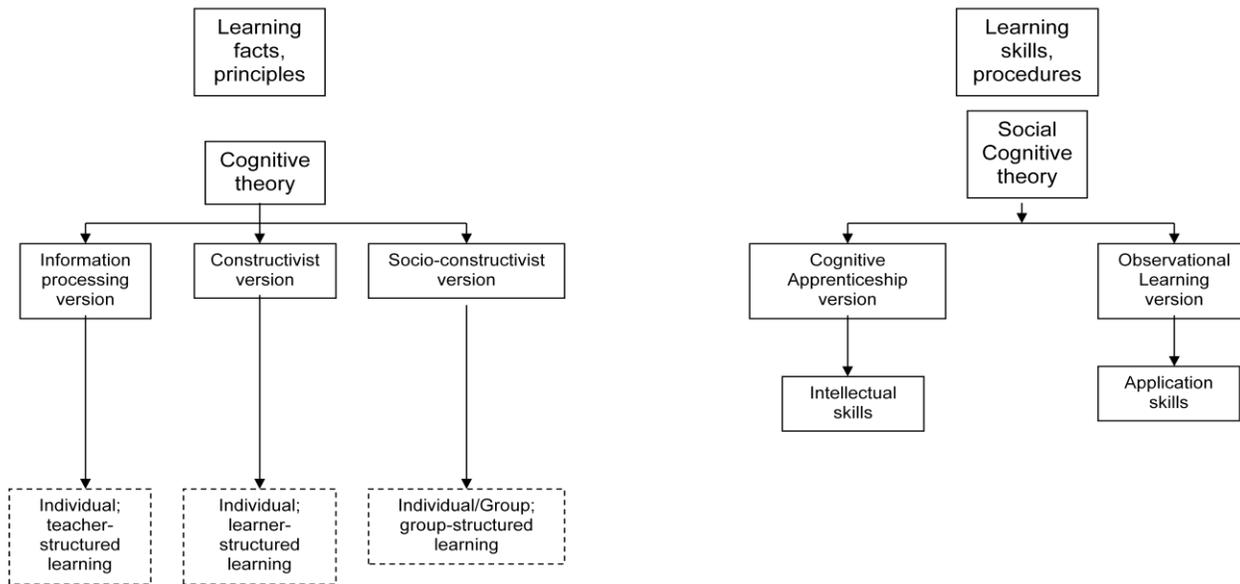
Most research in education derives from questions about learning: what is it and what affects it. All four of the frameworks in the HPL model address these questions, but usually faculty are more focused on student-centered and knowledge-centered aspects of the learning process. So this first set of research questions that faculty asked focus on those theories.

*How can I improve retention of information?*

*Does (intervention X) improve student understanding?*

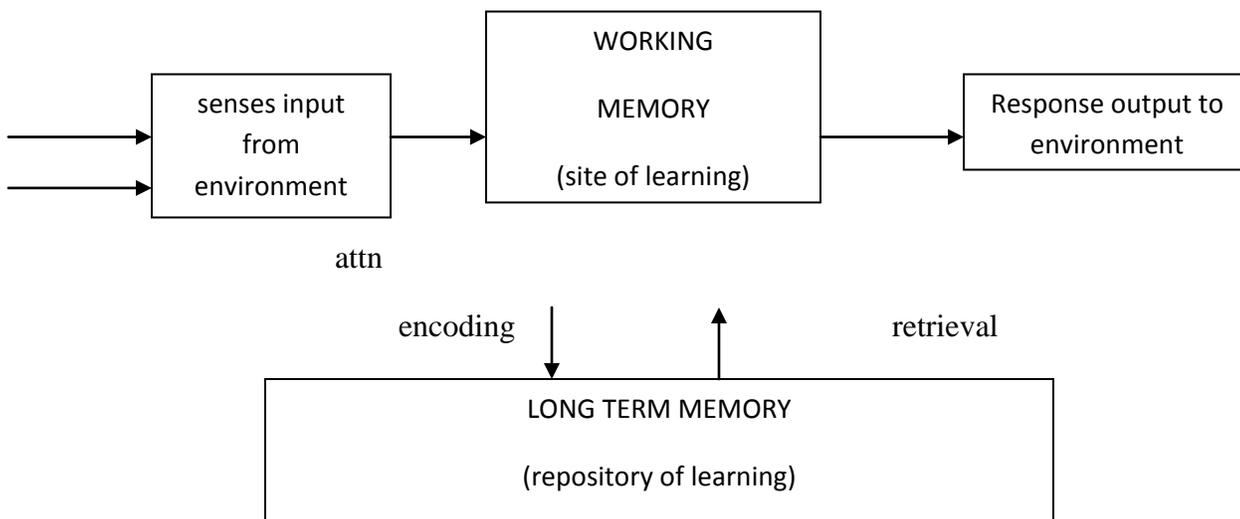
The above questions both seem to revolve primarily around this interest in what is learning and how it is affected by instruction. In reality, many questions that seem to be about learning end up being about motivation, too. But for now we'll just concentrate on learning and memory: what they are and what affects them. I will say that almost all the theories in this guidebook come down to some variant on cognitive theory, so it pays to understand this one well.

Figure 2: Learning Theories Concept Map



*Cognitive theory and its attendant phenomena (left side of Figure 2)*

The most prevalent model of content learning today is one that addresses how new information is taken in and stored in memory for future use. Virtually all versions of learning theory have this as their foundation. The details may differ slightly, but the big picture is the same. The diagram below shows one way that the cognitive process in learning is depicted.



Information coming in from the environment first registers on the senses. Through the process of selective attention, some of that information gets through into working memory while the rest is discarded. Working memory is where the learning action is. In working memory, things that are

present at the same time or in close proximity get connected and modified in a way to make it possible for them to be stored as long term memory. This process also depends a lot on the learners' prior knowledge (what's already in long term memory) and the kinds of connections that can be made with those memories and what you want them to learn. This process is called "encoding" in the literature. It refers to the way that new information is transformed into something that can be connected and/or stored in long term memory for later retrieval. Encoding usually involves the following:

1. filtering the informing information in some way so that the gist of it is left (for example, summarizing, paraphrasing, clustering information).
2. organizing the incoming information in some way that makes it workable.
3. making that organization or gist memorable in some way by making it stand out from the background noise or by finding already familiar things to attach it to.

Things that are in long term memory can be retrieved into working memory to be acted on further, to be connected to new information or to cause a response to the environment. This is, of course, a horribly oversimplified version of the theory, but it makes several important points.

1. Information has to impact the senses to even get into the system.
2. There is a filtering process between the senses and working memory, which can be manipulated so that some chosen things get through while others are ignored.
3. If something doesn't get into working memory somehow, it's not going to get into long term memory.
4. Things in working memory get hooked up with things in long term memory, a process that can be manipulated.
5. The structure of information in long term memory is what learning is all about. Getting that structure right is critical to instruction and it can be manipulated by what happens during learning.
6. If you can't get it out of long term memory so it can affect responding, what good is it?

Instructional manipulations of learning deal with getting things from the outside environment into working memory and then getting them connected to the structures and memories that already exist in long term memory. Who or what is in charge of all of this is the subject of some debate.

**Figure 2** shows how the various cognitive theories are related to one another.

- **Information processing theorists** assert that the process just described is fairly automatic, such that what ends up in long term memory is a reflection of what came in through the senses; therefore, the instructional process is pretty much in control of the instructor ("what they see is what they get").

- **Constructivist theorists** on the other hand assert that the learner is the one that determines how long term memories are constructed (hence the name of the theory) and the final form of memories are more a function of what already exists in long term memory, how the learner interprets new information, and how the learner forms the connections and formats the content as it heads into long term memory (“what the learner THINKS he sees is what he gets”). This process is not necessarily a conscious one, but it goes on all the time.
- **Socio-constructivist theories** (Brown and Campione, 1994) are like constructivists in that they think it is the learners who drive the learning, but in this case it is a group of learners (“what the LEARNERS agree they see is what they get”). This last theory is one of the underpinnings of collaborative learning and therefore is getting a lot of press recently.

At this point, however, the constructivists are ahead in the voting. If you’re interested in pursuing this further, information about these theories would be provided in the basic textbooks in educational psychology I mentioned earlier as well as in my book. There are also more detailed references included at the end of this section.

### **What does all this mean for you as an educational researcher?**

If I were to approach the research questions raised at the start of this section from a cognitive perspective, I would be looking at those aspects of instruction that affect the points in the cognitive model where instruction can influence learning and therefore retention. In general I would look at:

1. what prior knowledge the student has about the new content to be learned: how much, how accurate, what format is it in, what it consists of;
2. how the learners’ attention is directed toward the critical components on the new content to be learned;
3. how the instruction uses what the learners already know to help them make connections with the new content;
4. whether the amount of content being presented at one time is too much for the learners’ working memory to handle and therefore what instruction is doing to relieve some of the working memory load;
5. how the “gist” of the new content is structured or encoded so that it would be easy to store and retrieve from long term memory (this would be a big concern);
6. whether there was a sufficient amount of practice with the new content to ensure that it could be retrieved fairly readily;
7. and whether the learner received timely and sufficient feedback on their understanding of the information to be able to make changes if they wanted to.

## Readings on cognitive theory

Bransford, J. Stevens, R., Schwartz, D., Meltzogg, A., Pea, R., and others (2006) “Learning Theories and Education: Toward a Decade of Synergy” in Alexander, P., and Winne, P. (Eds.) Handbook of Educational Psychology. 2<sup>nd</sup> edition. Mahwah, NJ: Lawrence Erlbaum Publishers.

Greeno, J., Collins, A. & Resnick, L. (1996) “Cognition and Learning” in Berliner, D. and Calfee, R. (Eds.) Handbook of Educational Psychology. New York: Simon & Schuster MacMillan.

Ormrod, J. (2008, 5<sup>th</sup> edition) Human Learning. Upper Saddle River, NJ: Pearson Prentice Hall. Chapters 8-10.

Schraw, G. (2006) “Knowledge: Structures and Processes” in Alexander, P., and Winne, P. (Eds.) Handbook of Educational Psychology. 2<sup>nd</sup> edition. Mahwah, NJ: Lawrence Erlbaum Publishers.

Svinicki, M.D. (2004) Learning and Motivation in the Postsecondary Classroom. San Francisco: Jossey-Bass Publisher Chapters 2-3.

## 1B. Research on learning skills and procedures (Svinicki chapter 4)

Another large category of learning in college is the learning of skills, both application skills, like solving a particular type of problem or using a particular tool or rule in a given situation, and intellectual skills, like problem-solving in general or critical thinking or anything that has to do with thinking through a situation.

*What is (are) the best method(s) of presenting/teaching problem solving skills to freshmen engineering students?*

*How can I improve my students' critical thinking skills in my courses?*

*How do we improve the way students work in teams?*

*Does design across the curriculum help students become better engineering problem solvers than a "capstone design" course in the curriculum?*

The above questions deal with learning a skill, whether it is an intellectual skill like problem solving or design or a behavioral skill like working in teams. In each case the learners have to learn what the steps or components of the skill are and how and when to execute them. Another type of skill would be applying procedures to well-structured situational problems where what to do is known; the learner is simply applying that to this situation. Finally, there are some physical manipulation skills that are learned in labs or field settings. In each of these cases, even though they seem quite different in complexity, they still follow the same basic model with slight modifications.

*Social Cognitive Theory (formerly known as social learning theory) and its attendant phenomena (Right side of **Figure 2**)*

I believe that the best theory to help researchers ask questions about skill learning is based in what is now called Social Cognitive Theory, but which was originally called Observational learning theory. This theory holds that a lot of procedural learning is best done through observation of others followed by practice with feedback. Regardless of the skill being taught, the following four areas need to be incorporated in the learning plan for it to work well.

1. The learners' attention must be drawn to and focused on the critical components of the skill to be learned as it is being demonstrated by another person (also called "the model"). This can be done by simplifying the demonstration so that only the most important basic steps are shown initially, highlighting or exaggerating those key steps so that they are easy to observe, choosing the right person to demonstrate the steps (someone who is competent or similar to the learner), anything to help the learner distinguish the key points from incidental surrounding noise.
2. The learner has to create a mental image of the sequence so that the image can serve as the memory trace of the skill being learned. Sometimes this requires that the kinds of encoding strategies that were discussed under cognitive theory be used so that the mental image can be stored in long term memory. (At this point a perceptive reader may recognize that these are the same steps as the cognitive model says are the steps in learning. Good observation! This is, after all, the Social COGNITIVE theory. The "social" part of the name came originally from the observation of the other person who was engaged in the skill to be learned, hence its other name "observational learning.")

3. In the next step of learning, the learners actually practice the skill with coaching and feedback. Practice can be on individual steps or the entire skill, depending on its complexity. During this step the learners receive diagnostic and prescriptive feedback on their performance, either while it is occurring or in a debriefing session after it is completed. It helps for the learners to have a way of observing their execution of the skill. For physical skills this can involve some sort of recording, while for application of an algorithmic procedure, the learners can “show their work” by laying out all their steps or keeping a log of what they did.
4. As the learners become more and more proficient, they need less and less coaching and take on more responsibility for their own monitoring. Eventually they are able to complete the entire procedure without assistance and explain what they have done and why they did it that way.
5. The final step is demonstrating the skill in a new context, like working in a different environment or using a different version of the tool or solving a new problem with the tool/procedure.

The above outline applies whether the learners are learning an application skill or an intellectual skill. The biggest difference is in the first step, that of directing the learners’ attention to the key components of the skill. Obviously, if the skill is easily observed like operating a piece of equipment, there is no problem for the learners in seeing the key behaviors. However, most of our teaching in postsecondary education revolves around intellectual skills such as problem solving. It’s hard for the learner to observe the cognitive processes that are being demonstrated unless the instructor or the person doing the demonstrating thinks aloud during the process, narrating the steps as he or she goes along. This is the basis of the “cognitive apprenticeship” model. It adheres to the basic social cognitive sequenced but adds the narration as the teacher thinks aloud during a problem solution in front of the class. Most instructors already do narrate problem solving when demonstrating a solution type for the class, but many times they leave out important steps because they are so expert in the area that the steps are automatic. Or they go so fast that the students can’t keep up enough to create that mental model; they just write everything down verbatim and hope to go back to their notes later and figure out what the instructor was doing.

### **What does all this mean for you as an educational researcher?**

If I were to approach the research questions raised at the start of this section from a social cognitive perspective, I would be looking at those aspects of instruction that affect the points in the social cognitive model where instruction can influence learning and therefore performance. In general I would look at:

1. What strategies are being used to help the learners identify the key steps in the procedure they are learning and are those strategies effective?
2. Is the instruction structured in such a way that the learners are actually able to create and retain a mental model of the procedures that they can then use to prompt their later application of the procedures?

3. What are the conditions under which the learners are applying what they have observed? How similar are they to the learning conditions? Do the learners recognize them as a situation in which what they have learned should be applied? (This question gets into the area of transfer of learning, which is dealt with in a later section.)
4. What kinds of feedback (format, timing, content, source, etc.) are being provided during learning to help the learners improve their performance?

## Readings

Bandura, A. (1975) "Analysis of Modeling Processes" School Psychology Digest, 4(1), 4-10. You'll probably never be able to find this article, but it is one of the earliest ones in which the observational learning model is described.

Halpern, D. (1997) Critical Thinking across the Curriculum. Mahway, NJ: Lawrence Erlbaum Associates.

Mayer, R. and Wittrock, M. (1996) "Problem Solving Transfer" in Berliner, D. and Calfee, R. (Eds.) Handbook of Educational Psychology. New York: Simon & Schuster MacMillan.

Mayer, R. and Wittrock, M. (2006) "Problem Solving" in Alexander, P., and Winne, P. (Eds.) Handbook of Educational Psychology. 2<sup>nd</sup> edition. Mahwah, NJ: Lawrence Erlbaum Publishers.

Ormrod, J. (2008, 5<sup>th</sup> edition) Human Learning. Upper Saddle River, NJ: Pearson Prentice Hall. Chapter 7.

Svinicki, M.D. (2004) Learning and Motivation in the Postsecondary Classroom. San Francisco: Jossey-Bass Publishers. Chapter 4.

## Section 2: Theories about Learner Characteristics: More learner-centered framework considerations

The theories that we have just been considering deal with the process of learning itself, but that process is influenced by several other variable categories, most pressing of which is the learner. The qualities and characteristic ways of functioning that the learner brings to the process of learning are almost more important than how the learning is taking place, even though there is sometimes little an instructor can do to change them. So it is important for those embarking on educational research to recognize those variables and attempt to either “control” for them or build their effects into the research itself. The three that are most commonly thought of are:

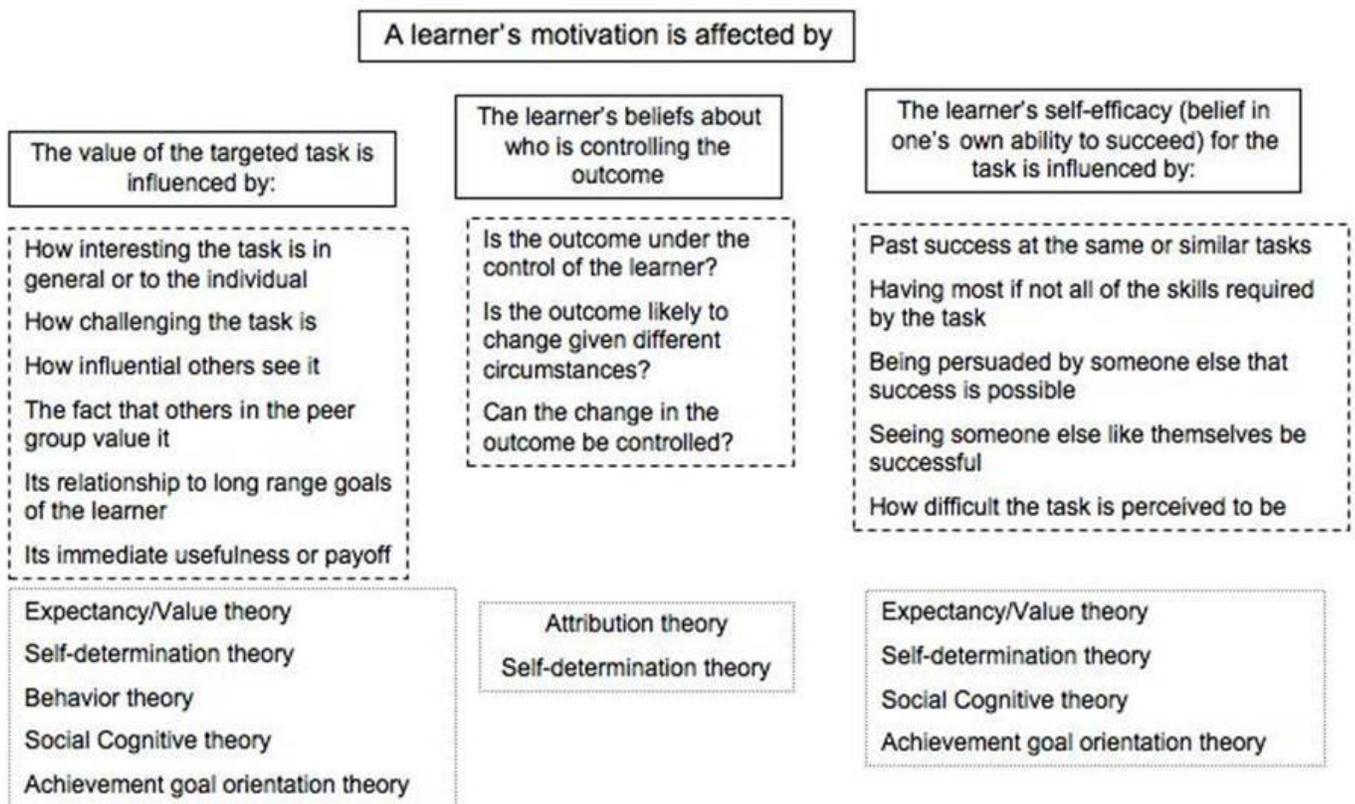
1. Motivation
2. Developmental stage
3. Learning preferences (usually called learning style)

We will now look at each of these in turn to see what considerations in design they suggest.

### 2A. Research questions about motivation (Svinicki chapter 7)

This is both the most interesting and least understood of the learner qualities that impact learning. The problem is, of course, that motivation must be inferred because it cannot be observed directly. Of course in some ways that’s true of learning itself, this was the argument of the Behaviorists. We are forced to use observable behavioral measures that imply motivation (working harder may be a result of higher levels of motivation) or self-report measures (asking learners if they’re motivated). Neither choice is optimal. Nevertheless, our own personal experiences convince us of the validity of the concept and the necessity of factoring it into our understanding of learning. What I’m going to do is point to the motivation theories that are most involved in learning and as a result should be considered in research on learning. The overall combined motivation theory that I use is shown in **Figure 3** and is discussed in great detail in Svinicki (2004) chapter 7. Here we’ll have just the outline to point in the right direction.

Figure 3: A Combined Motivation Theory



Current motivation theories, like current learning theories, are grounded in thinking. How the learner interprets what is happening around him or she is the source of motivation. If the learner thinks that something is worth doing, motivation will be high, even if the thing itself has no real value (like videogames, for example). Because the learner thinks they are important or valued by his peers, he will be motivated to play the games until his fingers seize up. If the learner thinks something is worthless or doesn't understand it's worth (like calculus, in my opinion), he will have to be externally motivated by something outside him, like grades. It's important to remember that it's the learners' interpretation that counts (except for life and death issues).

*How do you ensure students adequately follow all of the steps of the design process in project assignments and in capstone design courses?*

*What can be done to improve students' attitudes about learning (motivation)?*

*How do I motivate students to do homework?*

The above questions all deal with what motivates students to engage in the behaviors that the instructor thinks are important. Like our learning questions, which were actually instructional design questions, these questions are phrased more to help instructors with better teaching strategies than to research basic motivational properties or processes. However, we can turn them into research questions if we ask them in terms of "why" because why students do things or fail to do them are often motivation questions. If we understand "why", we can usually get to "how" to change things. In this section we're going to examine the different explanations of why people do things and place those theories in the context of engineering education.

The overriding instructional interest in motivation is what impacts student motivation. In the literature on this topic, there are many theories, but for our purposes they all point toward the same three forces: the value of the learning, the learners' interpretation of what causes success or failure, and their expectations of being able to be successful. Interventions that impact any one of these three should affect learner motivation, unless the other two are at zero. I'm going to describe all the theories listed in the bottom boxes of **Figure 3** and show how they relate to these three areas and research on them.

### *Expectancy/Value Theory (Eccles, 1983)*

This theory asserts that if the learners believe they can be successful at the task they are being asked to do, their motivation to do it is higher (the expectancy part). It also asserts that if they think the task is worth doing, their motivation to do it is higher (the value part). If either of these is missing, their motivation will be lowered. If the learners in the situation you are studying show low levels of motivation, then research questions can be formed around the kinds of things that are affecting one or the other of these two forces.

A possible research question might be "Is the failure of students to complete homework assignments related to low levels of motivation, and if so, what type of manipulation (value or expectancy) would provide sufficient increase in motivation to improve the completion rate in a normal class?"

I added that first part because failure to complete homework may have nothing to do with motivation and everything to do with time available. However, we can proceed with the research on what would get students to do their homework and use the motivation theories as the framework for choosing the variables to manipulate. For example, low motivation may be the result of the nature of the task; the task itself may not be interesting. Drill and practice tasks are the kind of uninteresting tasks that tend to lower motivation. On the other hand, case studies are often inherently interesting because they are related to the learners' long term professional goals or their complexity is challenging. We would hypothesize that if course concepts could be illustrated and practiced using case studies as homework as opposed to drill and practice homework assignments, students would be more motivated to do them. On the other hand the way most instructors choose to manipulate the value of the task is to offer some immediate payoff like points. We could certainly design a research study to investigate at whether offering extra credit or making the homework more interesting resulted in more homework getting done, for example. We could also design a study to see how much extra credit would be necessary to overcome the boredom associated with drill and practice homework and under what conditions. (Actually there's an interesting research strain about just this type of hypothesis being done by Csikzentmihalyi, 1990, around the concept of "flow", the point of maximum intrinsic motivation.)

On the other side of Figure 3, expectancy for success (self-efficacy) at a task is another contributor to success. Homework might not be getting done because the students believe that no matter how hard they try, they'll never get it right. If the homework is just too difficult, why waste time struggling with it? Of course, research also shows that a little struggle is a good thing, but too much struggle results in low motivation. As researchers we could manipulate the difficulty of the homework to see at what point the learners give up. That doesn't sound like a very good teaching strategy, however. But teaching and research may sometimes be at odds at the beginning.

*Self-determination theory (Deci & Ryan and others, 1991)*

This theory revolves around the degree to which learners believe they have choice and control over their actions, they are competent to complete a task and they are part of a community of support and belonging. When they have choice and control, they are more likely to select activities that are both interesting and doable (thus reflecting value and expectancy respectively), which increases motivation. Because they have chosen the task or some part of it, they are likely to select things they feel competent in, which increase motivation. And because they feel they are part of community engaged in a task, they are empowered to act, which is an increase in their motivation.

A research question we might ask would be “Would students who are allowed to select the topic of their final project be more likely to work consistently and complete the project on time, and produce a product of higher quality?” I have actually had a graduate student study this question in a physics lab course. She manipulated the degree of choice the students had; some students had an open ended choice; others had to choose from a list of topics; and the third group were assigned the project topics that the first group chose (presumably the topics were the same difficulty in both cases, but one group had choice whereas the other didn’t; this is called a “yoked control” procedure).

*Behavior theory (Skinner)*

This is the old psychology theory you might have studied in your undergraduate days. Technically, this is not a motivation theory, but the manipulation of rewards and punishments is what passes for motivation in behavior theory. And this is certainly how most faculty think about motivation – the bigger the point value, the higher the motivation. As you can see from Figure 3, this theory is listed under the task value category because that is what you are manipulating when you change the credit or penalties of assignments. Behavior theory has a lot of predictions about the way to deliver reinforcement and punishment to make it more or less effective and any one of these predictions could form the basis for a research study on student motivation to do homework. For example, if you want students to pay particular attention to an aspect of the homework (like following the steps in the design process), that’s what you would make the most reinforcement (points) contingent on. Or if there is a particularly bad habit that you want to get rid of in students (like failing to follow instructions), that’s what would get the biggest deduction in points. Those are the most obvious variables one could research, but there are other predictions in behavior theory that would be interesting, too, like timing the reinforcement (which is better: immediate or slightly delayed?).

On another note, there is an entire area of theorizing that is opposed to the use of behavior theory as the basis of influencing student behavior. For example, there is some evidence that students become too focused on the external rewards to the detriment of their attention to the task itself. That conflict has made for some very interesting research. In fact there is a whole motivation theory around this conflict and it is the next one on the list.

*Achievement Goal Orientation theory (Dweck & Leggett)*

This theory is a little more complex than the ones I’ve just described, but it asserts that when students are working towards a goal, their motivation is affected by the way they think about what they’re trying to accomplish (their goal orientation). This theory is relatively new and is undergoing modifications as I write,

but at this point, the theory says there are four possible orientations that students might be adopting toward their work.

1. Mastery orientation – these are the times when they are really focused on learning. When adopting this orientation, learners will keep on trying and be willing to try anything that will help them learn whatever they’re working on. This orientation is generally viewed as the most positive and desirable one to take.
2. Performance Approach orientation – these are times when the focus is not on learning for its own sake, but learning in order to get some end outcome, like a high grade or being the best in the group. Although this is still a powerful motivator, it is directed toward the wrong thing if the learners become too focused on the end recognition and not what they have learned in the process.
3. Performance Avoidance orientation – sometimes learners are being very cautious during learning in order to avoid making any mistakes that might make them appear incompetent. This is generally considered a bad orientation to adopt.
4. Work Avoidance orientation (I call this “strategic effort” to make it sound better) – Here the learners are balancing payoff with effort. They’re trying to minimize what they have to do.

A research question that arises from this theory might be “Are students who are characterized by a mastery orientation to engineering more likely to want homework that illustrates complex structural issues than students who adopt a performance approach orientation?” As the researcher you would administer one of the goal orientation inventories that exist and compare self-report evaluations of satisfaction with homework. Then if you find that mastery oriented students DO prefer complex homework, you might see what you can do in terms of course structure to encourage all students to adopt that orientation. That is where the field is right now.

### *Social cognitive theory (Bandura)*

Note that this theory shows up in both the learning area and now the motivation area. That’s because social cognitive theory has components that deal with both. The theory in its original form (observational learning or social learning theory) had a whole structure having to do with what is called vicarious reinforcement or punishment. You’ll recall that what was taking place during learning was that the learners were observing someone else demonstrating the behavior to be learned and as a result creating a mental image of that behavior. Social learning theory said that the learners also were observing what happened to the person demonstrating; they saw that person either be successful and reinforced for their success or if the behavior was a negative one, they were punished and the learner observed that as well. This “vicarious” experience then influenced whether or not the learner went ahead with the behavior being observed. This is one part of the motivational aspect of social cognitive theory. Learners who observe another person being rewarded will be more motivated to engage in that behavior themselves.

The other part of social cognitive theory that is relevant to motivation is the concept of self-efficacy, the belief that an individual has about his or her ability to perform a certain task. This is like the expectancy part of expectancy/value theory. A learner who believes in his own ability is more motivated to perform. Self-

efficacy can be both a contributor to motivation and a result of an intervention. We can increase or decrease a learner's self-efficacy by the way he or she is treated, for example. Self-efficacy is one of the individual variables that are most highly correlated with achievement.

A research question based on this theory would be similar to the expectancy/value questions on the expectancy side. "Do students with high self-efficacy for mechanics choose more complex homework problems even when they receive the same amount of credit as problems of less complexity?" Or if you chose to study the vicarious reinforcement aspect of the theory, you might use group work in which an initial task was demonstrated successfully with one group, which then received a positive appraisal by the instructor, and then measure the degree of amount of activity displayed by the other groups during the same task.

### *Attribution theory (Weiner)*

This is actually the hardest of the theories to understand and the one most closely associated with psychology from the outside perspective. It is used mostly to offer an explanation of why someone responds to a situation in a certain way because it is based on the individual's beliefs about how the world works. So we might say that someone is not motivated because he believes (that's the attribution part) that the teacher is grading preferentially and doesn't like him; hence, he will never be able to get a good grade. Or the learner might be unmotivated because he believes that he has no "math ability" and therefore cannot ever be successful as an engineer. Beliefs about causes of outcomes (the teacher's preferential grading system or a lack of math ability) revolve around several characteristics of those causes.

1. Is the cause/outcome likely to change given different circumstances? If it is, there might be more motivation to do something about it. This is referred to as the stability of the cause.
2. Can the change in the cause be controlled if it occurs? This is referred to as controllability. Controlled causes are likely to be more motivating because it implies that something can be done.
3. Would the change be under the control of the learner? If it is, the learner is more likely to be motivated. This is referred to as internal vs. external location of control.

One problem with attribution theory is that there is often little that an instructor can do to change a long held belief by a learner. It can be done, but it takes a long time and a lot of individual attention. So, in general, attribution theory is used to explain rather than being manipulated itself. A research question therefore, might be something like "Do students who receive consistent negative feedback on their work and explain the results in a way consistent with external attributions show a greater tendency to turn work in past the due date than students who receive the same negative feedback but make internal attributions?"

In looking at **Figure 3** you can see how these different theories relate to our three main variables in motivation. Each theory offers a set of variables that are expected to impact motivation in some way. Since, as noted earlier, a lot of learning questions also have an implied motivational aspect, you might consider always making it a habit to consider the level of learner motivation when interpreting research results.

**What does all this mean for you as an educational researcher?**

If I were to approach the research questions raised at the start of this section from a motivational perspective, I would be looking at those aspects of instruction that affect the three main variables in motivation. In general I would look at:

1. What are the value components of the task/materials being learned and how are those made evident to the learners;
2. What are the qualities of the learners' situations that impact the value of the learning;
3. What are the learners' expectations about their own abilities to be successful at the task and how are those impacted by the instructional situation;
4. What are the beliefs about cause and effect that the learners hold and what impact are they having on the learners' willingness to engage in learning.

## Readings

Bandura, A. (1997) Self-Efficacy: The Exercise of Control. New York: W.H. Freeman.

Deci, E. L., Vallerand, R.J., Pelletier, L.G. & Ryan, R.M. (1991) "Motivation and education: The self-determination perspective" Educational Psychologist, 26, 325-346.

Dweck, C.S. & Leggett, E. (1988) "A social-cognitive approach to motivation and personality" Psychological Review, 95, 256-273.

Eccles (Parsons), J. (1983) "Expectancies, values, and academic behavior." in J.T. Spence (Ed.) Achievement and Achievement Motivation. San Francisco: W.H. Freeman.

Ormrod, J. (2008, 5<sup>th</sup> edition) Human Learning. Upper Saddle River, NJ: Pearson Prentice Hall. Chapters 15-16.

Pintrich, P. and Schunk, D. (2002, 2<sup>nd</sup> Edition) Motivation in Education: Theory, Research, and Applications Upper Saddle River, NJ: Merrill Prentice Hall. This is a good overall reference for anything having to do with motivation.

Stipek, D. (1996) "Motivation and Instruction" in Berliner, D. and Calfee, R. (Eds.) Handbook of Educational Psychology. New York: Simon & Schuster MacMillan.

Svinicki, M.D. (2004) Learning and Motivation in the Postsecondary Classroom. San Francisco: Jossey-Bass Publishers. Chapter 7.

Weiner, B. (1985) "An attributional theory of motivation and emotion." Psychological Review, 92, 548-573.

## 2B. Theories about developmental stage (Svinicki chapters 6 & 8)

Another source of individual differences among students has to do with developmental issues. The assumption in this area is that learners are at different places in their intellectual development and some may be more “ready” than others to tackle the kinds of questions that are important to engineering work. This difference may be a general developmental phase (similar to Piagetian child cognitive development) or it may be related to a particular discipline (similar to the expert/novice literature). And there are several developmental models that are related to maturity and personal development

*What elements of (how do) [exercises, exam questions, small projects, format, structure, information included or left out] encourage development of higher-level thinking by students?*

*How can one account for the student mindset towards compartmentalizing prior course work in upper level courses that require synthesis of foundational topics? By "account for" I mean assess where the student is and move them forwards to more skill and acceptance of responsibility or ownership of knowledge.*

*What types of pedagogical approaches tend to lead to higher intellectual development? Undergraduate research, service learning, integrated design experience?*

Underlying these questions is the idea that there are levels of thinking, some of which are “higher.” Earlier we talked about encouraging critical thinking as an intellectual skill and approached the question from the learning perspective. Here we’re going to discuss the developmental aspect of this problem. It does appear from the literature that students go through phases in which they think about problems in different ways. Some say this is a developmental/maturational issue such that more complex thought processes flow naturally from simpler processes; others maintain that it is experience and awareness that produces the change. From a research perspective there are three main areas of development that would be interesting to study: 1. development of expertise in a given discipline; 2. cognitive development; and 3. epistemological development.

*Model of Domain Learning (Alexander)*

The research on the development of expertise (Chi, Glaser and Farr, 1988) has been of great interest to the engineering community. While a lot of this research has been done contrasting the problem solving of experts vs. novices, its results haven’t had much to say about the import of this difference for instruction, other than to say the two groups think differently about problems. It has shown that you can’t make someone an expert by just giving them more information; there is a different quality to an expert’s thinking and it involves developing a structural understanding of the area, not just learning more details. However, there is one model of learning that addresses how learners actually get from one level to another and it is called the Model of Domain Learning. By Domain Learning, Alexander meant the knowledge that one has about a particular discipline. In her Model of Domain Learning, she combines this knowledge with the motivational forces that impact its learning (i.e. interest) and the learning strategies that facilitate its acquisition in order to understand the stages that learners experience in becoming more proficient in an area. These stages are:

1. Acclimation – This is the initial state of the learner who is just entering a domain; he has little base knowledge of the area and what he has is not organized in any way, consisting mostly of isolated bits of information. Alexander refers to this as “unprincipled” knowledge because the learner has not yet been exposed to or learned the significance of the principles of the discipline. The theory offers a lot of

possibilities for understanding how to support learners at this stage. One example is that teachers of students at this stage often confuse them by discussing what is interesting to the teacher rather than what is important to learn. Students at this stage don't have good rules for recognizing the difference.

2. Competence – Learners at this stage have begun to recognize the important principles of the discipline and organize their understanding of it around those principles. Yes, they have more knowledge to work with, but more important it is organized knowledge which can guide further learning. An interesting side benefit of developing competence is that the learner can do more of the mundane tasks of the discipline automatically and leave more thinking resources available for dealing with the novel or the unknown. In addition at this stage the learner is more committed to learning and therefore more mastery-oriented. They also have developed domain-specific strategies for learning that make it easier because they can deal with the idiosyncrasies of the content of the discipline; they actually learn how to learn in the discipline.
3. Proficiency/Expertise – The final stage is that of expert. Individuals who reach this level have great repertoires of highly organized knowledge and efficient strategies for dealing with it, and high levels of intrinsic motivation to learn more.

For a firsthand feel for the MDL think about how you personally are processing all the new information in this field of educational research. The Model of Domain Learning has a lot of implications for educational research in the disciplines and has proven to be quite useful in helping to form hypotheses about the relationship between instructional practice and learning.

#### *Models of Cognitive Development (Hofer and Pintrich)*

Piaget was probably the most famous proponent of the idea that cognitive ability progresses through stages of development. He proposed that children begin at a very concrete level of interacting with the world. As they get older, their ability to interact at a more complex abstract level develops until they are able to abstract the rules of the world from the concrete examples and use them to solve new problems. Although Piaget held that this development was essentially complete by about 12 years old, later researchers began to find evidence that when Piaget's stages were applied to college students, some had not made the shift to abstract thinking yet. Even today some speculate that the stages of Piagetian development mirror what happens any time a learner moves into an unfamiliar content area. When you are new to an area, you need and want concrete examples; later you come to appreciate the principles behind the examples.

Perry's cognitive development model: Of course, Piaget was working with children, but a more adult oriented cognitive development theory is that of Perry (1970) who was working with college students. In his exploration of how learners dealt with the subjects they were learning, Perry found that students appeared to be characterized by four stages. The first he named dualism because thinking was very black or white, right or wrong. As students were exposed to more of the shades of gray in college, their approach became what Perry called multiplicitic, to reflect their belief that every interpretation was right to someone and therefore there was no "right" way to do anything. Eventually students learned that circumstances determined that some choices were more appropriate than others, a relativistic perspective. The final stage that Perry proposed he called relativism with commitment. In this stage the learners acknowledged the possibility of multiple interpretations but had chosen one that had been demonstrated to be plausible to them. Perry said that very few students reached this final stage of development. The significance of a cognitive development theory like this one is that research and instructional outcomes are influenced by the mindset that the learner brings to the table.

Perry would speculate that it is difficult to get dualists to acknowledge the complexity of some situations before they have been prepared for it.

Epistemological development: There is also another area of theorizing that supports this stage of cognitive development and that is the area of epistemological beliefs. These are beliefs that learners hold about knowledge and learning itself. For example, one belief that is in line with Perry's model is a belief in the certainty of knowledge – that knowledge is fixed and not something that will change over time. Often students who hold such beliefs are looking to someone to tell them what the right answer is and they become impatient with uncertainty and ambiguity. Other beliefs are the nature of ability (that ability is either fixed or can be changed), the speed of learning (learning proceeds very rapidly and if you don't get it right away, you never will) and so on. For work in this area in the science disciplines, I recommend looking at Schommer (1994) who has attempted to develop instruments to assess students' cognitive development in the sciences. For a very complete discussion of these developmental theories, I direct you to Hofer and Pintrich, 2002, which describes and critiques these various theories.

### **What does all this mean for you as an educational researcher?**

If I were to want to consider the questions that appeared at the start of this section from a developmental perspective, I would want to get an indication of where along any developmental continuum the students fell at the onset of instruction and then again after the instructional intervention had been implemented. One nice thing about developmental differences is that the descriptions of the different phases also frequently give hints about the types of experiences that will move students along toward higher levels of functioning. Most developmental theories recommend that to help students think at a higher level, the instruction has to confront the inadequacies of their current reasoning and offer them an alternative that represents the higher level. In general I would look at:

1. What level of cognitive development are the students at when starting the course?
2. What types of reasoning skills are required at the next level of development?
3. How does a proposed instructional intervention challenge the students' existing beliefs and attitudes about knowledge and direct them to the next level?

### **Readings**

Alexander, P. (1997) "Mapping the multidimensional nature of domain learning: The interplay of cognitive, motivational, and strategic forces." Advances in Motivation and Achievement, 10, 213-250.

Baxter-Magolda, M.B. (1992) Knowing and Reasoning in College: Gender-related Patterns in Students' Intellectual Development. San Francisco: Jossey-Bass Publishers.

Hofer, B. and Pintrich, P. (2002) Personal epistemology: the psychology of beliefs about knowledge and knowing. Mahwah, NJ: Lawrence Erlbaum Associates.

Perry, W. G., Jr. (1970) Forms of Intellectual and Ethical Development in the College Years: A Scheme. New York: Holt, Rinehart and Winston.

Schommer, M. (1994) “Synthesizing epistemological belief research: Tentative understandings and provocative conclusions.” Educational Psychology Review, 6, 293-319.

Svinicki, M.D. (2004) Learning and Motivation in the Postsecondary Classroom. San Francisco: Jossey-Bass Publishers. Chapter 6 & 8.

## 2C. Theories about individual differences in learning (Svinicki, chapter 8)

From a psychologist's perspective this is one of the hardest areas to deal with because it has so much face validity and very often, little psychometric validity. I have discussed my general feelings about this area in chapter 8 of the Svinicki (2004) book. The concept is that students have different preferences when it comes to taking in and processing new information; therefore some of the differences we see in student performance are a function of a mismatch between their learning style and the instructional format. This is a very appealing assertion to most people. We've experienced it ourselves; we need an explanation why the same instruction produces such different effects in students; we like to categorize people (think astrological signs). However, in general the theories and models that have been put forth do not have sufficient psychometric integrity that one would be able to use the data they produce in research because you would end up violating all kinds of statistical assumptions about reliability and validity.

At the end of this section I have included in the readings some compilations of research and theory on individual differences of all sorts. Particularly comprehensive is the book by Ackermann and his colleagues, which brings in a lot of general intelligence research, personality and attitudinal issues, cognitive differences, and some of the methodological issues that make this such a complex area to study.

### *Learning style theories (Felder and Silverman)*

If you would like to read about a very well-thought out model for individual differences, I would recommend the Felder/Silverman Index of Learning Styles, one that is familiar to a lot of engineering faculty. Or at least read about it in Felder and Spurlin (2005). They describe the psychometric properties of the ILS and provide a very good discussion of its strengths and weaknesses.

### *Individual differences that make a difference*

I'm pretty sure that my discussion about learning style left you feeling dissatisfied. It usually does. That is the conflict between our private experiences as learners and the ability of our discipline to measure those experiences reliably. So, while I can't recommend you try to research learning style as a source of individual difference, I can recommend some other areas of individual difference that are more objectively measurable and therefore probably more likely to be able to play a role in your research on engineering education. Some we've already touched on; others we have not.

**Prior knowledge** – If there's one thing that I'm sure of, it is that the wide range of differences in prior knowledge amongst learners accounts for a huge amount of the variability in learning outcomes. So figure out what the students should know and measure that as part of the research design.

**Motivation** – This is another slam-dunk. Motivation is a huge contributor to individual differences, not just how much motivation, but also the direction it takes. We've already discussed some of these alternatives.

**Self-regulation of learning** – There is also a range of students' knowledge about alternative ways of learning and of their ability to monitor their own learning. Research has shown that students are not great at recognizing when they don't understand and even less accomplished at knowing what to do about it. There are

instruments that are based on cognitive theory's version of learning strategy knowledge that have been used widely as covariates in research.

Epistemological beliefs and level of development – We've already discussed this area, too. It's a little harder to pin down, but it influences how learners go about interpreting and carrying out their learning tasks.

### **What does all this mean for you as an educational researcher?**

If I were to approach the research questions raised at the start of this section from an individual differences perspective, I would be looking at those aspects of the learner that might intersect the learning outcomes I wanted to study. In general I would look at individual differences as pre-existing conditions that mediate the impact of any instructional intervention on the learning outcome. For example, the level of a student's motivation could make it less likely that assigning additional homework would enhance understanding even if the student actually does the homework. This is because motivation levels often impact the degree of mindfulness that a learner has during a given task. Less motivation, less mindfulness, less learning even with the same amount of work.

It is possible that you might look at changes in some of these variables as outcome measures themselves. For example, many of the research questions our engineering colleagues raised about motivation dealt with a desire to affect it directly in hopes that it would lead to better learning (an assumption they were making). In those cases you need to measure the level of the variable present before the intervention and after the intervention to see if there was a change. A caution, however. These individual difference variables are not that easy to change in a single course; it usually requires several courses to edge the students along in these areas, at least in a way that is sustained. One can often create temporary changes that are related to the learning circumstance, but there is no guarantee that those changes will last.

### **Readings**

Ackerman, P., Kyllonen, P., and Roberts, R. (1999) Learning and Individual Differences: Process, Trait, and Content Determinants. Washington, DC: American Psychological Association Press.

Felder, R. and Silverman, L. (1988) "Learning and teaching styles in engineering education." Engineering Education, 78(7) 674-681.

Felder, R. and Spurlin, J. (2005) "Applications, reliability and validity of the Index of Learning Styles" International Journal of Engineering Education, 21(1), 103-112.

Riding, R. and Rayner, S. (1998) Cognitive Styles and Learning Strategies. London: David Fulton Publishers.

Sternberg, R. and Zhang, L. (2001) Perspectives on Thinking, Learning, and Cognitive Styles. Mahwah, NJ: Lawrence Erlbaum Associates.

Svinicki, M.D. (2004) Learning and Motivation in the Postsecondary Classroom. San Francisco: Jossey-Bass Publishers. Chapter 6 & 8.

## Section 3: Theories about the content to be learned: The knowledge-centered framework (Svinicki, chapter 3)

*What are some good design strategies for implementing Bloom's taxonomy in standard engineering courses, i.e. the foundation courses such as thermodynamics, circuits, etc.?*

*Can students master design without considerable hands-on experience conducting design activities?*

*What are the habits of mind or modes of thinking that are unique to engineering, i.e. what does it mean to be an engineer?*

*Do concept inventories help them learn concepts better?*

### 3A. Research on levels of cognitive complexity models

Although learning processes stay pretty much the same across learning situations, the content and the context change and contribute to differences that instruction and research need to attend to. Some research and theorizing in this area has been trying to capture the nature of learning in various disciplines in an effort to tie it to the processes of teaching and learning.

#### *Bloom's Taxonomy*

The most famous taxonomy in education is Bloom's Taxonomy of Educational Objectives for the Cognitive Domain (Bloom, 1956), which was actually one of three taxonomies developed at the time. The other two were taxonomies for the Affective Domain and the Psychomotor Domain. The former has to do with attitudes and values and the latter has to do with physical manipulation of the environment, as in operating equipment or performing motor tasks. In general the book describing the Cognitive Taxonomy is also a pretty good resource when it comes to designing either activities to encourage performance at various levels or assessments to measure whether a student can perform at a given level. Because this Taxonomy is so well known, I won't say anything more about it. I'd just encourage the budding researcher to go back to the original printed copy and read through it. You'll find it very enlightening. The Taxonomy has recently been updated and changed slightly by Anderson, Krathwohl, et al, one of the original authors of the Affective Domain Taxonomy (2002). Krathwohl and his colleagues turned it from one dimensional taxonomy to a two dimensional taxonomy crossing the kind of knowledge being considered with the level of understanding required. So you could say that someone had very basic knowledge of facts at a memorized level or at an understanding level. The benefit of this Taxonomy for researchers is that it provides a common language to use in discussing what is being learned.

#### *The Taxonomy of Significant Learning Experiences*

This is a more recent attempt to classify learning outcomes was provided by Fink (2003). This Taxonomy also has six types of learning but this set is as follows:

1. foundational knowledge
2. application
3. integration

4. learning how to learn
5. caring – developing new feelings, interests, and values
6. the human dimension – learning about oneself and others

Like Bloom's Taxonomy the Taxonomy of Significant Learning is intended to be a guide to the design of learning experiences. However, it, too, can become a common language with which to discuss the knowledge-centered perspective in learning.

### *Concept Inventories*

These are in general attempts to create an assessment that codifies the main concepts of a discipline so that comparisons across instructional methods and student learning can be made. It began in physics and has been picked up by other disciplines, but creating that much consensus is very difficult despite what might appear to be fairly consistent ideas by experts. Creating an inventory implies that there are fundamental principles which are not going to change in the near future and which are critical for understanding the rest of the field. We'll see in the next part of this discussion how disciplinary differences might make it impossible to create such inventories in fields that are ill-structured or rapidly changing. In addition the process for generating a concept inventory has been relatively haphazard and even one as widely used as the force concept inventory has its problems. Attempts to validate the psychometric properties of the inventory have run into problems (see Huffman and Heller, 1995). However, the application of good measurement theory to the attempt could help.

There is actually a process for producing and evaluating a concept map of a domain. The process involves having students and experts rate concepts for their relationships with one another. The data produced by this rating can then be analyzed by a computer program (Pathfinder) to develop a graph of the connections among the concepts (Schaneveldt, 1990). This master graph can be compared to student or expert concept maps to measure the degree to which they match. Kellogg, et al (2004) discusses how these graphs have been validated and used in various disciplines.

### **3B. Research on differences in disciplinary thinking**

It seems very clear to anyone who has worked in a cross-disciplinary context that there are differences about the way different disciplines think about knowledge, learning and thinking. Efforts to research these differences and to study the impact those differences have on teaching would be another source of interesting study for engineering educators. There are two models of working in the disciplines that could be used to inform both research and teaching. One deals with disciplinary differences in thinking; the other with a model for encouraging faculty and students to take those differences in account when teaching or learning.

#### *Differences in critical thinking in the disciplines*

This model was one of the earliest attempts to study the way experts and novices in different fields think. The leading researcher, Janet Donald, interviewed faculty in a wide range of departments to help her understand their expectations for students (Donald, 2002). She studied their course designs and assignments to help her understand how those were informed by the way the instructors thought about their field. She subsequently also studied how students interpreted the requirements of their courses and how their thinking about the field

was shaped by those courses. Of special interest to the readers of this guidebook is the fact that engineering was one of the fields included in the study. Donald categorized the disciplines according to several taxonomies, including whether the domain was a well-structured domain like mathematics or an ill-structured domain like psychology. She along with several other subsequent researchers found that the nature of the discipline made a big difference in how students were expected to learn and think, showing that some instructional processes were more suited to one type of discipline than another.

### *Learning to decode the discipline for students*

In subsequent years specialists working in faculty development wanted to help faculty design instruction that would “decode” the discipline for their students. Middendorf and Pace (2004) developed a model to help instructors open the often unstated assumptions and perspectives of their discipline so that students could understand it more readily, especially those coming from a different base. Without having these assumptions and perspectives articulated for them, students coming into a very specific discipline like engineering from the kinds of general courses found in most general education curricula could appear to be ill-prepared while really they are just accustomed to approaching problems differently. This was shown a while back by Sheila Tobias (1990). She showed that even skilled learners have a hard time moving across disciplines.

### **What does all this mean for you as an educational researcher?**

If I were to approach the research questions raised in this section knowledge-centered perspective, I would be looking at the goals and structure of the content that students are grappling with to see if there is an interaction between some of the learner-centered characteristics described earlier and the knowledge-centered characteristic we’ve just discussed. In general I would look at:

1. What are the key ideas in the field and are they integrated into the course assignments and activities in a way that might affect what I am researching;
2. Whether there are differences across those concepts and how students respond to them that might give me some ideas about student thinking and learning and how it changes during the course of a semester or over the curriculum;
3. What qualities of learning beyond the content are part of the process in learning the discipline and do they affect the results of what I am researching;
4. What are the differences between the way the field thinks about problem-solving and the way students think about it and are those differences having an impact on student behavior;
5. What are the most important qualities of thinking that a student in engineering needs to have early on in his or her studies to be successful throughout the rest of his or her tenure at the university and how are they being assessed or built into the curriculum at the appropriate time.

### **Readings**

Anderson, L. Krathwohl, D. Airasian, P., Cruikshak, K., Mayer, R., Pintrich, P., Raths, J. & Wittrock, J. (2001) A Taxonomy for Learning, Teaching, and Assessing: A revision of Bloom’s Taxonomy of Educational Objectives. (Complete edition). New York: Longman.

- Bloom, B. (1956) Taxonomy of Educational Objectives: Classification of educational goals. Handbook 1: Cognitive domain. New York: Longman, Green & Co.
- Donald, J. (2002) Learning to Think: Disciplinary Perspectives. San Francisco: Jossey-Bass Publisher.
- Fink, L.D. (2003) Creating Significant Learning Experiences: An Integrated Approach to Designing College Courses. San Francisco: Jossey-Bass Publisher.
- Huffman, D. and Heller, P. (1995) “What does the force concept inventory actually measure?” The Physics Teacher, 33, 138-143.
- Kellogg, R., Friedman, A., Johnson, P. and Rickard, T. (2004) “Domain-specific Knowledge in Intellectual Skills: A Symposium in Honor of Lyle E. Bourne” in A. Healy (Ed.) Experimental Cognitive Psychology and Its Applications. Washington, DC: American Psychological Association.
- Middendorf, J. and Pace, D. (2004) “Decoding the Disciplines: A Model for Helping Students Learn Disciplinary Ways of Thinking.” New Directions for Teaching and Learning Series, no. 98, San Francisco: Wiley & Co.
- Schaneveldt, R. (1990) Pathfinder Associative Networks: Studies in Knowledge Organization. Norwood, NJ: Ablex.
- Tobias, S. (1990) they’re not dumb, they’re difference: Stalking the second tier. Tucson, AZ: Research Corp

## Section 4: Theories about the way learning is assessed: The assessment framework

The spirit of the assessment framework is that learning is best when there is ongoing assessment and feedback. Incorporating mini-test like events in the course of instruction serves the formative evaluation purpose of assessment as well as taking away some of the fear factor associated with evaluation. Although there are many aspects of assessment that can inform educational research, I'm just going to describe a few of the ones most tightly connected to learning: objectives-based assessment, the concept of "desirable difficulties," and authentic assessment. Both actually help deal with the lack of transfer that we often see and which was the basis of several research suggestions from our engineering colleagues.

### 4A. Research on the design of assessments

*What are the best assessment practices? How to use the results of assessments?*

*Can online tools such as Blackboard be used as a measure of a student's tendency to lifelong learning?*

*What factors best predict a student's college success?*

*How do I determine if the tests I'm using are really getting at what I intended them to?*

Most engineering faculty is already very familiar with the use of objectives in the design of instruction and evaluation. When objectives, instruction and assessment all line up as focusing on the same learning outcomes, learning is much more efficient. There is no reason in this guidebook to go into depth about evaluation design, but there is one design process that is useful in doing research on the assessments themselves. That is the process of "backward design," a concept quite familiar to many engineers. The theory is that one should start with the final product of learning and work backwards to identify the measurements and instructional strategies that will result in that end product. As a research tool, such an analysis might identify components of the learning that are resulting in an unintended result or it might suggest assessment possibilities that can be built into the learning without additional effort on the part of either the learner or the instructor. For more about "backward design" as applied to assessment design, I suggest looking at Wiggins and McTighe's (1998) *Understanding by Design*.

*Transfer failure: The 800 pound gorilla in the middle of the learning room (Svinicki, Chapter 5)*

*How can we help students understand the applications of math in mechanics courses, especially statics and dynamics?*

*How can we help students to transfer/retain knowledge from pre-requisite courses to the next levels?*

*Why do students forget what they learned in previous classes (i.e. why do they not integrate their learning?)*

*To what extent does what I teach transfer to "real world" environments?*

In the learning arena this big area of applying concepts outside the context of the original learning is called **transfer**. It is a constant problem in education at all levels, and learning theories have tried to explain it in multiple ways, none very satisfactory. Most revolve around two factors in transfer: first is the degree to which the two situations involve similar components (they appear to be similar or they follow the same rules of problem solving); second is the degree to which the learners are primed to transfer (in psychology we say they have a "transfer set" or they are metacognitively engaged to expect transfer opportunities). Currently this whole area is under study, but there are some general principles that can be used to think about research in this

vein. For more comprehensive discussions of transfer research you can consult Svinicki (2004) chapter 5 or the Bransford, Brown and Cocking (1999) *How People Learn* volume.

### *Situated learning theory and authentic assessment*

One of the most comprehensive current theories of transfer is Situated Learning theory, also called Contextual theory (Greeno, Collins, and Resnick, 1995; Wilson and Myers, 2000). In this theory whatever is present during learning becomes a part of what is learned, including the context. When the learner is in a different context, some of the stimuli associated with the learning are not there. As a result, the learner is not responding to the same situation and the response called for is no longer the same response. The original response learned is said to be “situated” in the original learning environment. To deal with this issue, theorists have urged that learning be done in a context as close to the eventual application context as possible. This is referred to as “authentic learning.” If the learner can be trained in such an environment, then more of the cues that are needed to transfer are present during learning and the probability of what is learned being available for use later is increased. In general the use of real case materials during learning is one example of how situated learning can be used to the learners’ benefit. This is also the basis for the concept of “authentic assessment,” the use of real life situations as evaluations of learning. Authentic assessment has other benefits, too. Because it is as close to the real thing as possible, it can often uncover misconceptions that don’t show up in the tidy testing situations using abstract problems because authentic situations tend to be messy and not so clear cut that they point to the solution in a rote way. Also because they look like the real thing, they often are more motivating for students, who can now see the connections between what they are learning and their long range goals.

### *Metacognitive engagement or Mindful learning*

The other area of research that is of great interest to transfer theorists is the idea that learners are more likely to transfer what they have learned if they are aware of the need to transfer, “metacognitive<sup>1</sup> engaged” or “mindful”. Early research on transfer indicated that learners do NOT automatically transfer even mildly complex skills to new situations; they have to be “set” to look for transfer and sometimes even that doesn’t happen. However, if the learners are cognitive engaged (looking for the possibility of transfer) they might recognize the patterns present in the new situation and attempt to apply what they have learned.

There are some situations where transfer is automatic, but these involve a lot more practice than we normally give our students. However, to give you an example, think about reading. When a person is first learning to read, every letter, every word has to be sounded out to be understood. With more and more practice, reading becomes automatic and closer to pattern recognition than to learning new words, unless the word being decoded is particularly unusual or long or unfamiliar (i.e. it reverts back to sounding out because no pattern already exists). However, the amount of practice in reading that has to occur to reach that level of proficiency is enormous (no wonder it takes so long and some kids give up). This particular concept also underlies a lot of the research on expertise. The idea is that experts have had so much exposure to a content area that they have seen almost everything before and are mostly engaged in pattern recognition rather than real problem solving.

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<sup>1</sup> Metacognition is a component of cognitive theory and refers to the executive processes that make it possible for a learner to direct his or her own thinking and learning. Part of it is being aware of what you are doing cognitively and the other part is having alternative ways of solving problems you are trying to address.

The alternative to automatic transfer is mindful transfer. In mindful transfer the learner extracts and transfers the larger rule that the initial learning situation is an example of. It is understanding the rule rather than recognizing the exact situation that enables transfer.

Instructors have to operate under the assumption that transfer is not automatic, but needs priming. Therefore activities at the start of each unit should emphasize for the students how what is being learned is connected to what has been learned. You can see from the questions at the start of this section how both the need for more thorough learning and more connections between learning and transfer situations have to be built into the learning activities.

#### 4B. Research on feedback from assessments

##### *Feedback characteristics*

One of the advantages of formative assessment is that it can set the stage for feedback to have an effect on learning. Most instructors have had the annoying experience of spending time providing written feedback on student work only to have the students focus almost exclusively on the grade and pay no attention to the feedback. Feedback has always been an important component of all learning models including the cognitive model discussed earlier, so there is quite a bit of research on what makes for effective feedback. As an educational researcher you might want to think about the structure of feedback that occurs in your instructional situation to understand the possible impact it might have. A good meta-analysis of the research on feedback during learning was provided by Bangert-Drowns, et al in 1991. Those researchers made some interesting findings, including identifying situations in which feedback is actually a detriment to learning. In addition to being a good check on research design, the consideration of what feedback is provided in a system could be an interesting research focus as well.

##### *Peer assessment and feedback*

The advent of socio-constructivist theory in learning and the popularity of collaborative and team-based learning have raised the issue of the validity, reliability and impact of peer assessment. Fortunately there have been some meta-analyses done on these processes somewhat recently. The reviews provide both the theoretical rationales for peer assessment and feedback and in one case taxonomy of peer feedback. Topping (1998) concluded that “organized, delivered, and monitored with care, it (peer feedback) can yield gains in the cognitive, social, affective, transferable skill, and systemic domains that are at least as good as those from staff assessment.” (pg. 269). He suggested that means needed to be found to make the system more efficient. Recently some progress has been made in using technology to assist the instructor in monitoring and calibrating peer review of writing in chemistry classes, a technique described by Kovac and Sherwood (1999). A later meta-analysis on peer assessment in higher education was conducted by Falchikov and Goldfinch (2000) and included both self- and peer assessment in the analysis. In light of the interest in collaborative learning, research should be pursuing the impact of different kinds of peer feedback on learning and motivation.

## What does all this mean for you as an educational researcher?

If I were to approach the research questions raised in this section from an assessment and transfer perspective, I would be looking at those aspects of instruction that affect the similarity between the ultimate goals of the instruction, the learning situation and the eventual application of that learning and ways in which learners are being made more mindful about the need for transfer. In general I would look at:

1. What is the correspondence between the measures that instructors are using to assess learning and the actual goals of instruction;
2. Where in the learning process can assessments be inserted to further learner progress;
3. What kinds of authentic learning situations are possible given the constraints of the instructional setting;
4. What kinds of learning activities direct the learners' attention to the underlying rules or structure of the content or skills being learned;
5. What kinds of learning activities encourage students to make connections between previously learned material and the present situation;
6. What kinds of learning activities encourage students to review and preview what they've learned and what they are about to learn;
7. What kinds of learning activities would create a "transfer" set in the mind of the learner throughout his or her education;
8. What types of assessments can be used as both a learning and an evaluation tool in instructional designs.

## Readings

Bangert-Drowns, R., Kulik, C., Kulik, J. & Morgan, M. (1991) "The instructional effect of feedback in test-like events" Review of Educational Research, 61(2), 213-238.

Bransford, J., Brown, A. and Cocking, R. (1999) How People Learn: Brain, Mind, Experience, and School. Washington, DC: National Academies Press.

Falchikov, N. and Goldfinch, J. (2000) "Student peer assessment in higher education: A meta-analysis comparing peer and teacher marks." Review of Educational Research, 70(3), 287-322.

Greeno, J., Collins, A. & Resnick, L. (1996) "Cognition and Learning" in Berliner, D. and Calfee, R. (Eds.) Handbook of Educational Psychology. New York: Simon & Schuster MacMillan.

Haskell, R. (2001) Transfer of Learning: Cognition, Instruction, and Reasoning. San Diego, CA: Academic Press.

Kovac, J. and Sherwood, D. (1999) writing in chemistry: An effective learning tool Journal of Chemical Education. 76(10), 1399-1403.

Svinicki, M.D. (2004) Learning and Motivation in the Postsecondary Classroom. San Francisco: Jossey-Bass Publishers. Chapter 5.

Topping, K. (1998) "Peer assessment between students in colleges and universities." Review of Educational Research, 68(3), 249-276.

Wilson, B. and Myers, K. (2000) "Situated cognition in theoretical and practical context" in Jonassen, D. and Land, S. Theoretical Foundations of Learning Environments. Mahwah, NJ: Lawrence Erlbaum Associates.

## Section 5: Theories about the effects of community in the classroom: the community-centered perspective

The original discussion of this perspective in the HPL framework included both the classroom and the homes and communities surrounding the learners and the degree to which those forces influenced student learning. Since the research in that book dealt with the entire range of education from pre-kindergarten to postsecondary, it was logical to include all aspects of the community, including the family. Since the focus of this guidebook is on postsecondary education, I'll constrain my discussion of the possible communities to the immediate classroom and the community of engineering practice within the institution. (Another important community to consider would be the connections to the wider community of practitioners in the field; however, I am not qualified to address those issues.) What kinds of theories inform research you might consider with regard to these areas?

### 5A. Research on the classroom environment as a community

*Is peer instruction (or student-centered learning activity) more effective than traditional instruction methods (lecture, slides) for students who are repeating a course? Or if students have failed a course taught with peer instruction, would it be better for them to retake the course with the same teaching format, or with traditional instructional methods?*

*How does team environment affect student's ability to learn (insert a topic here?)\_*

*What approaches best teach students how to be successful team contributors?*

*What are the most important factors to consider when forming student teams for cooperative learning?*

*How do you assign teams and give them guidance?*

*How do members of under-represented groups [experience, cope with, perceive, anticipate] [group work, team assignments] in engineering classes?*

#### *Collaborative learning*

Since the primary readers of this guidebook are going to be engineering faculty, you'll be pleased to know that one of the experts in this area is one of your own, an engineer, Karl Smith. Karl and the Johnsons of Minnesota are probably the first people to turn to to read about collaborative learning. I recommend *Active Learning: Cooperation in the College Classroom* (1998).

I'll provide you with another resource, one closer to my own expertise. In the latest edition of the *Handbook of Educational Psychology* (2006) Angela O'Donnell has provided a very good overview of the research and theory around peer and group learning. In it she discusses many of the theories that underlie what happens in

peer learning, including cognitive theory, social cognitive theory, socio-constructivist theory, and social psychology. She deals with the composition of groups, pairs vs. groups, and the roles of teachers and students.

One line of research that I think would be particularly interesting is to separate out the influences of active learning versus peer learning. Obviously all peer learning is active, but not all active learning needs to be done in groups. This would pit the constructivist against the socio-constructivists in terms of which learning process is most important: personal long term memory construction or negotiation of meaning with others. I don't know if anyone is doing this yet.

A change in the method for researching this topic has also occurred somewhat recently. Initial research on this topic looked at fairly macro-units of analysis, such as performance on the final exam or end of semester survey. More recently, researchers who take a more ethnographic, qualitative approach are looking more closely at this type of learning and trying to decipher what is actually happening in the groups themselves. This involves recording or observing groups as they work through a problem and attempting then to analyze the actual discussions that students have and what they tell us about cognitive processing. This is a very time-consuming research method, but it does get at the actual behavior of students. For example, in a research study that I am doing with some graduate students right now, we have found that the hope for thoughtful conversation and deep processing in groups is futile in many cases. The level of intellectual discussion, even of difficult problems, tends to be fairly superficial and more focused on getting the question "right" than understanding the issues. Surveys don't get at that kind of information in general (although one of the goals of this research is to see if we can).

#### *Research on classroom community and climate*

This is another of the areas of my own research, which is still in its infancy. Certainly we have studies of ethnicity and gender issues affecting the classroom climate and those are very important to engineering faculty, as shown in the next section. However, it is just as important for all students that the classroom be perceived as a safe place in which to take the risks involved in learning. Most community research in postsecondary education is being done by student life specialists and focuses on the campus climate (Tinto; Pascarella and Terenzini; Kuh). The research that I do and that I think is more relevant to faculty is focusing on making every classroom a community where students feel like they belong and are going to be supported by their peers and the instructor. I believe that if we can do this, all students will benefit. I'd like to be able to give you readings on this research, but it's too new. What does exist is mostly related to the lower grades (Bateman) or online communities (Rovai). However, many of the collaborative learning writers speak to the need for such safety and support and the reasoning behind it, which echoes the reasons for building a community in your own classroom. In my own research, we have elected to base our model on three elements that must be considered to study community in the classroom: 1. student to teacher interactions; 2. student to student interactions; and 3. group commitment to a common goal of learning and interest in the content. This mirrors on a micro scale the findings of Pascarella and Terenzini about student success in college in general. Research on the strategies for exploiting these connections in teaching would be a good place to look for what impacts student persistence.

*What are the primary reasons students leave engineering? Advising, mismatch in learning style vs. curriculum, curriculum too passive....?*

*How to motivate under-represented minority groups to pursue higher degrees in engineering?*

*What support mechanisms provide best retention of undergrads?*

*What do we as a college environment need to do to best support our undergrads?*

*How does my curriculum impact the "engineering identity" of my students?*

*The community of practice in the institution and beyond*

Of all the question topics that were submitted by our engineering education colleagues, the topic of retention of students and diversifying the engineering student population were the most frequently mentioned. This is obviously a widespread concern and an urgent one as well. It's also one of the hardest to study because there are so many factors, individual, disciplinary, and institutional, that impact it. At the learner-centered level, all the factors discussed in the previous sections of this guidebook are potential research topics: strategies for learning, motivational differences, prior knowledge and skill proficiencies, and learning preferences, just to name a few. And studying this phenomenon at the level of the individual still won't necessarily make it easier to predict who will stay and who will go. That can only be done at the composite level. At the knowledge-centered level, the structure of the discipline probably plays a big part in whether or not students learn and remain, but it is probably the hardest for those on the inside to study because to them it is implicit, tacit, and mostly unavailable for examination. I do think that at the assessment-centered level, there may be ways of changing typical assessment procedures to make them more attractive to a wider range of students. For example, a move to authentic testing may draw in more of the students who have different reasons for wanting to be engineers, reasons more associated with what being an engineer can do for society than with either the mathematical or technical side of the discipline. However, it has been and will probably continue to be the community-centered perspective that holds the most promise for understanding how to attract and retain students. Below are some of the theories that might inform the research into this aspect of engineering education.

**Communities of practice:** One of the practical lines of research that has come out of the socio-constructivist theories is the idea of learning within a community of practice. Although the technical description of communities of practice is quite complex in terms of the learning processes that are proposed to take place within them, the concept of joining a community and the phases involved in the process are not that difficult to grasp. Think of it as "the collaborative, contextualized and concrete character of learning outside of school, as opposed to the individual and abstract character of learning that occurs inside of school." (Barab and Duffy, 2000, pg. 28) Communities of practice (Lave & Wenger, 1991) consist of individuals working collaboratively at multiple levels of competence on common problems, using common vocabulary and ways of thinking and doing toward a common goal. An apprentice joins the community by observing the more skilled practitioners, by starting with simple, but authentic, tasks and gradually taking on more and more responsibility until he or she can be considered a practicing journeyman in the field. This process of authentic learning is very different from what students usually experience in college classes: a sort of abstract, distant body of knowledge that has to be mastered out of context. The forces operating in communities of practice are similar to those just described for classroom communities, but they encompass the profession's norms so they go beyond the classroom and into the profession itself. Thinking about engineering education as the ongoing participation in a community of practice might give clues as to why some individuals stay and others go. For example, if an individual of a minority group does not see himself or herself as a member of that community, either because

of his or her own perspectives or because of the activities of community that exclude him or her, staying in the field will not be a productive experience. The problem is that those who are already within the community sometimes have difficulty recognizing that others are being kept at a distance, however inadvertently.

These issues of socialization into the discipline are being studied in many professional disciplines, including teaching, medicine and nursing among others. In addition, the National Science Foundation's program, Research Experiences for Undergraduates, is based on the notion that students learn science best by doing it rather than just hearing about it. (Hunter, Laursen & Seymour, 2006). When students work in a team with more advanced students on an authentic research program, there are cognitive, affective and personal benefits. This notion of active participation in the life of the institution or the field echoes the research on student persistence (Tinto, 1998). Those students who become part of the process are much more likely to stay. This general idea is rich in possible research studies and could possibly point the way to answer the questions that are posed at the start of this section. Tinto (1988) even provided a three stage model of leaving and joining that could help researchers look for points of intervention. The three stages are 1. separation from the previous community; 2. transition to the new community setting and 3. incorporation into the community. Tinto was using this model to discuss the general tendencies of students to leave higher education, but they are just as valid in discussing why students don't stay in a major.

Social Cognitive Career Theory: A related model that might be useful in researching student major choice and satisfaction is Social Cognitive Career Theory proposed by Lent and Brown, 2006. This theory is related to Bandura's Social Cognitive (learning) Theory that was discussed in the very first section of this guidebook. In applying SCT to educational decisions, Lent and Brown propose that there are six key elements: 1. educational satisfaction; 2. personality and affective traits; 3. goals and goal-directed activity; 4. self-efficacy; 5. situation conditions and outcomes; and 7. goal relevant supports, resources, and obstacles (Lent and Brown, pg 238). This model provides a rich source of research ideas for studying why students chose to study engineering and why they persist or not.

### **What does all this mean for you as an educational researcher?**

If I were to approach the research questions raised in this section from community-centered perspective, I would be looking at those aspects of instruction that affect the degree to which students are integrated into the classroom, the major and eventually the field. In general I would look at:

1. What are the qualities of student to student and student to instructor interactions that increase the perception of community in the classroom;
2. what processes in collaborative learning are important to which aspects of learning and motivation in general and to specific educational goals;
3. What activities result in students' opportunities to participate in the community of practice within engineering;
4. What happens to student perceptions of satisfaction with engineering when instruction focuses on incorporation of the student into the community of practice within the field;

5. What are the individual differences among students and circumstances that are related to incorporation of a given student into the profession.

## Readings

Barab, S. and Duffy, T. “From practice fields to communities of practice” in Jonassen, D. and Land, S. Theoretical Foundations of Learning Environments. Mahwah, NJ: Lawrence Erlbaum Associates, pg. 25-56.

Hunter, A., Laursen, S. and Seymour, E. (2006) “Becoming a scientist: The role of undergraduate research in students’ cognitive, personal, and professional development.” Science Education, published online 12 October 2006 in Wiley InterScience, DOI 10.1002/sce 20173.

Johnson, D., Johnson, R, and Smith, K. (1998) Active Learning: Cooperation in the College Classroom. Edina, MN: Interaction Book Company.

Lave, J. and Wenger, E. (1991) Situated Learning: Legitimate Peripheral Participation. New York: Cambridge University Press.

Lent, R. and Brown, S. (2006) “Integrating person and situation perspectives on work satisfaction: A social-cognitive view.” Journal of Vocational Behavior, 69, 236-247.

O’Donnell, A. (2006) “The role of peers and group learning” in Alexander, P., and Winne, P. (Eds.) Handbook of Educational Psychology. 2<sup>nd</sup> edition. Mahwah, NJ: Lawrence Erlbaum Publishers.

Pascarella, E. and Terenzini, P. (2005 2<sup>nd</sup> edition) How college affects students: A third decade of research. San Francisco: Jossey-Bass.

Rovai, A. (2002) “Building sense of community at a distance.” International Review of Research in Open and Distance Learning. 3(1) (on-line)

Tinto, V. (1998) “Colleges as communities: Taking research on student persistence seriously.” Review of Higher Education, 21(2), 167-177.

Zhao, C. and Kuh, G. (2004) “Adding value: Learning communities and student engagement” Research in Higher Education, 45(2), 115-138.

## The Research Process

There are many ways that researchers come up with ideas for studying education. Sometimes they start with a classroom observation and look for a theory to explain it; sometimes they start with a theory and look for its applications in the classroom. Both of these pathways are made easier to traverse by having a clearer idea about the framework you are using to understand what is happening. Let's look into this a little more deeply.

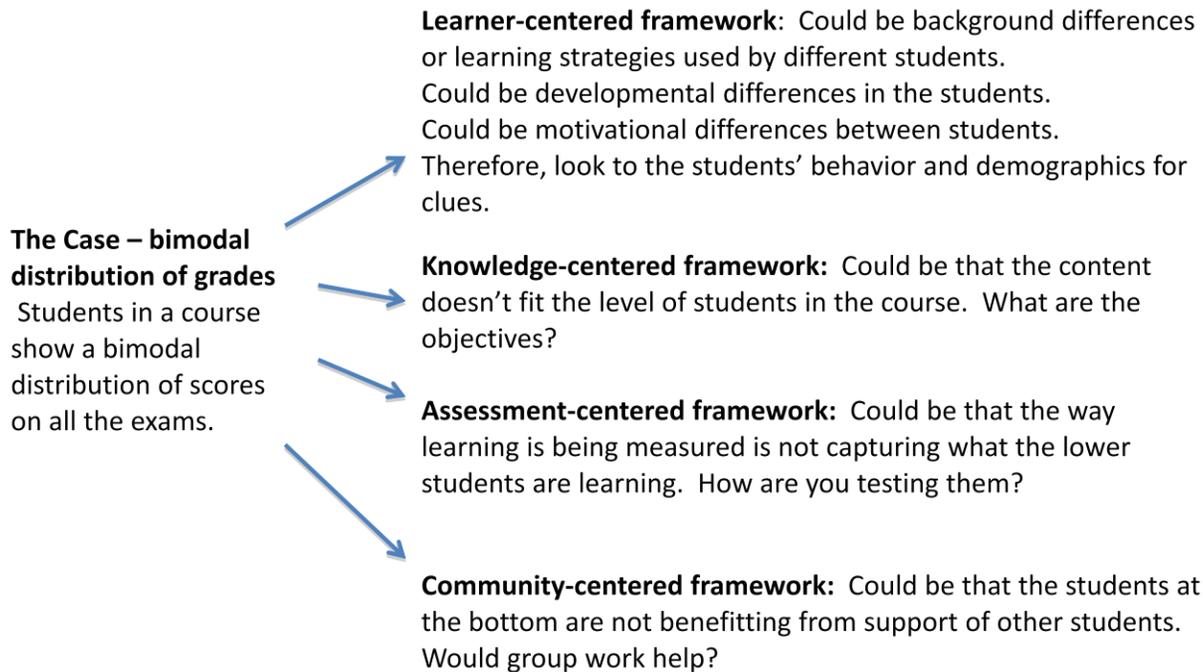
### Moving from observations to possible explanatory frameworks

Many times educational research arises from observations that teachers make in the process of teaching a class. The research would take different directions depending on which conceptual framework is shaping the researcher's thinking.

**The Observation:** Suppose you have noticed that there seems to be a bimodal distribution in the test scores of students in your class semester after semester; half of the students are getting as and Bs, the other half are failing, and there are very few in between. You think you are teaching the same material in the same way to all the students each semester, so why should there be a difference in performance?

How the framework you pick might shape your research. Here are a few examples of how various conceptual frameworks might inform this observation. (In each case we will explore just one or two theories here. Several others were discussed in the sections that preceded this one.) Look at Figure 4 as we explore how the frameworks might influence research.

Figure 4: How frameworks shape research



*Using a learner-centered framework: Is the difference one of learning, development or motivation?*

*Learning theories: Maybe you think the difference might be in how learners are learning so you choose components of a learning theory framework like:*

Cognitive theory

OR

Learning styles theory

If the learning that is supposed to happen in your class is knowledge of content, the conceptual framework that informs the actual learning best is Cognitive Theory and its various manifestations, such as information processing theory and constructivist theory. Cognitive theory would assert that either of the following underlying processes might be responsible for differences in learning among students (among other variables).

The amount learned and what is learned depends on the learner's prior knowledge. Therefore individual differences in prior knowledge appropriate to the concepts being learned could be the culprit in producing bimodal distributions. Administering a prior knowledge inventory that includes the pre-requisite knowledge for your content would give you information on who knows what. Then when you look at students in the two modes of your distribution, you will be able to see if they differ systematically with regard to prior knowledge. (Basic cognitive theory: the role of prior knowledge)

Or the amount learned could reflect different preferences in the way students are processing the content. There is some research on differences in learning preferences, although one shouldn't get a strictly bimodal

distribution unless something is else is going on. (Learning Styles Model: the role of individual differences in learning)

*Developmental theories: Maybe you think the difference might be in the intellectual level of the student so you choose a developmental theory like:*

Epistemological development theory

OR

Developmental level of self-regulated learning theory

Another way to frame this question is that the two peaks might represent differences in student development that happen to be present in the class. In this case Developmental Theory might provide the framework for understanding what is happening. Looked at this way, the following developmental differences might be responsible for differences in learning among students.

1. The amount learned and what is learned may depend on how the students think about what they are supposed to be doing in the class. That perspective on the goal of learning might result from their level of cognitive development. At some levels of development the learners believe that their goal is to learn whatever the instructor says and give it back verbatim. Other students take a more active approach to their learning, thinking of it as coming to understand in their own terms what the content is. The former students have a lot of trouble with test items that differ in any way from the way the content was taught; the latter students are often capable of changing the way they are thinking about the content because they don't see it as fixed but rather as changeable to meet the needs of the situation. (**Epistemological development theory**)
2. How the students have gone about learning can also be a source of difference that reflects development of the self as learner. Some students have only one way of approaching problems, whereas others have developed a wider range of strategies for approaching problems. (**Self-regulated learning theory**)

*Motivational processes theories: Maybe you think that the difference is in why the students are learning, so you choose to look at motivation theory, like:*

Self-efficacy theory

Expectancy/Value theory

One difference among students that everyone is familiar with is motivation and the impact it has on learning. There are several ways to think about motivation and how it affects a student's performance. Looked at this way, the following might be responsible for differences for learning among students.

1. Some students may be entering the class with a strong pre-existing belief in their own inability to learn this type of content. Despite being successful they continue to doubt themselves and sometimes in the process sabotage their own success by not acting in ways that would be compatible with learning. (Self-efficacy theory)
2. Some students fail to see any value in what they are supposed to be learning, which often leads to a lowered level of motivation. Lower motivation leads to less effort, which in turn leads to less learning. (Expectancy Value theory)

*Using a Knowledge-centered framework*

*Level of cognitive complexity models: Maybe you think that the difference might be in the material itself so you look at theories about content complexity like:*

Bloom's taxonomy of cognitive objectives  
Fink's taxonomy of significant learning  
Decoding the disciplines model of structure

Differences in student performance can sometimes be driven by the content itself and its characteristics. Researchers are developing ways of describing the complexity of the tasks being asked of learners and how that complexity interacts with learner characteristics.

1. The most well-known example of a model of cognitive complexity is Bloom's taxonomy of educational objectives. This model divides instructional goals into six levels of increasing complexity from rote knowledge to high level evaluation. It is possible that the cognitive level being demanded of the students in the class is pitched at a level of cognitive complexity that is workable for only half the class, leaving the others far behind no matter how hard they would try to learn. (Taxonomy of Educational Objectives).
2. Another example of a complexity model is the Taxonomy of Significant Learning proposed by Fink (2003). Like Bloom, Fink has six types of learning, but they include content, learning processes, learning about the self, and developing attitudes and beliefs. In this model the bimodal distribution could be a function of content that requires levels of self-regulation that some of the students have not yet developed. (Taxonomy of Significant Learning)
3. Disciplinary-differences in structure of knowledge. There are current theories that describe differences in the ways that different disciplines think about how knowledge is constructed and what constitutes "good thinking" including how knowledge is verified or evaluated. For example, what constitutes proof in the natural sciences is different from what constitutes proof in the social sciences, even though both strive for clean, valid and reliable results. Many times students familiar with one way of thinking about content have difficulty switching to another thinking framework. (Disciplinary differences in thinking processes; Decoding the Disciplines model)

*Using an Assessment-centered framework*

*Test design: You think the difference may be in the way learning is being assessed so you look at research on assessment like:*

Objectives based assessment  
Situated learning and authentic assessment.

1. Looking at the bimodal problem through the framework of assessment an instructor is usually examining how student learning is being measured in the class. For example, when tests and objectives don't match, the assessments sometimes turn into a moratorium on how well students take tests rather than on how much they know about the content. The bimodal distribution might actually be based on test-interpreting ability rather than content knowledge. (**Objectives-based assessment**)
2. Another possible assessment related impact might be coming from the ability of students to understand how principles they are learning are represented in authentic assessments involving real world problems. Students often have a very specific way of understanding a concept and when the assessment departs from that context, they don't recognize it as an example of the concept application (**Situated Learning and authentic assessment**)

*Using a Community-centered framework*

*The role of others: You speculate that the difference might lie in the lack of peer support that some students have or other situational variables, like:*

Socio-constructivist theory  
Distributed cognition theory

1. Some community-centered theories assert that things are learned through the process of interacting with others and negotiating understanding. Research and personal experience both support the observation that trying to explain what you think to someone else is a good way to decide what you think or why you think that. Therefore the bimodal distribution may be evidence of two different communities in the same class – one that is supported by collaborative learning and one that is not. (Socioconstructivist theory and collaborative learning)
2. Another theory that falls under the community-centered framework describes the classroom as a conglomerate of lots of different types of knowledge and levels of expertise, such that no one student holds all the information or understanding of a concept. Rather the class as a whole is the unit of learning with each student contributing to the overall performance of the class. Some students learn to take advantage of this fact and some do not. (Distributed cognition)

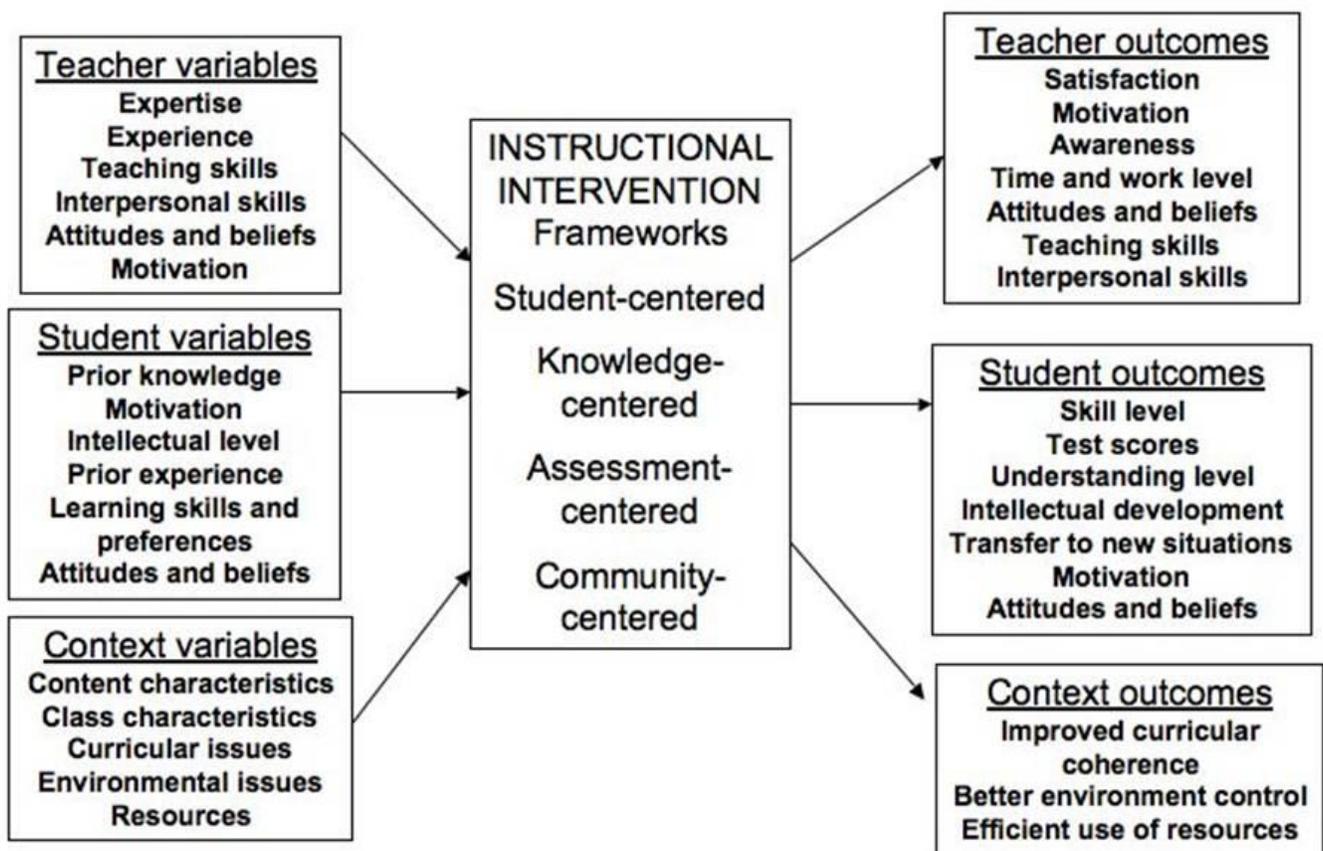
Any one or a combination of the above frameworks could help a researcher decide where to look for the bases of the bimodal distribution described earlier.

- The researcher might take a learner-centered cognitive perspective and look at the student backgrounds or learning strategies for a clue to the difference in the class and how to build on what's already there.

- A knowledge-centered perspective would encourage him or her to analyze the structure of the learning sequences to be sure that all students are following the logic of the course and content development.
- An assessment-centered perspective might involve doing a task-analysis of the assignments to see if they are matching the course goals as understood by the students.
- A community-centered perspective might suggest looking at ways of using the bimodal distribution to identify learning partners (one succeeding with one not doing well) and harness the power of peer learning.

Figure 5 shows the typical independent (input) and dependent (outcome) variables that are measured in educational research, just to give you ideas about what you might think about in designing your research questions.

Figure 5: Typical Educational Research Variables



In most cases unfortunately, it is a combination of these variables that are operating. This is one of the reasons that educational research can get so complicated. However, by thinking about these possibilities systematically, the researcher can be both creative and complete in the kinds of questions he or she asks.

## Moving from a framework to a possible instructional intervention

The examples I just gave you involve moving from an observation (the bimodal distribution) to the frameworks that might be involved (learner-centered, knowledge-centered, etc.). Sometimes research goes in the other direction: from framework to observation.

A concrete example: You learn about a self-determination theory that asserts that motivation is higher when the learner believes he or she is in control of the choices that affect his or her behavior. Learning about this theory you wonder if giving the students some choice over when and how they do some of the assignments in class might affect their motivation. And so you redesign the homework assignments to allow students to choose which five problems they have to hand in for each concept and observe their level of enthusiasm (or their lack of grumbling) about the homework. (Just as an aside, it WILL improve their motivation.)

## Framing the question

One final bit about questions you might consider asking in engineering education research, and this involves the complexity of the question. Just as is the case in engineering, nothing in education is ever so simple as “did it work or not.” That finding is usually only the tip of the iceberg. In reality, we are much more interested in questions that are structured like those in **Figure 6**. We ask not did it work or not, but rather under what conditions did a given input variable have an effect on a given outcome variable. And sometimes one input variable will affect an outcome variable one way, while another outcome variable is affected totally differently.

Figure 6: Typical Phrasing of Educational Research Questions

Not – Is X better than Y?

Should be – Under what conditions (context) will X (intervention) have a different effect on Z (outcome) than Y (intervention or control)?

Eg. For which students (context) will note-taking scaffolds (intervention) impact study habits (outcome) more than no scaffolds (control)?

Or

Eg. With which content (context) do student inquiry teaching methods (intervention) produce deep vs shallow understanding (outcome) in comparison to direct teaching methods (intervention)?

A concrete example: In the same example as above, giving students choices about which homework problems they turn in when may result in higher levels of motivation, but lower levels of performance. Then you are left with the question of which is more important: motivation or performance. There is no right answer to that question. However, it does highlight the fact that an important aspect of framing the question is deciding what your goals for instruction are and what you're willing to do to achieve them. It also highlights the fact that you have to be aware of the multiple forces that might be acting on your students' learning (for example, the absolutely guaranteed interaction between motivation and learning). It is a wise researcher who addresses each problem from a multiple framework perspective.

## Conclusion

The purpose of this Guidebook was not to give you everything you need to know about learning and motivation to do research on educational issues. That would be impossible for me to do and equally impossible for you to digest. Rather my hope was to alert you to some of the theoretical and research backgrounds that might be useful in thinking about why things happen the way they do in your classroom. I've pointed you in the right direction (I hope), but you are the one who must take on the role of scholarly researcher in engineering education. For more support in that area I recommend to you the faculty of the existing departments of engineering education first. Second I refer you to the work on the scholarship of teaching and learning being done by the Carnegie Academy for the Scholarship of Teaching and Learning ([www.carnegiefoundation.org/CASTL/index.htm](http://www.carnegiefoundation.org/CASTL/index.htm)) and the various subdivisions of NSF and the National Academy of Engineering and to the Journal of Research in Engineering Education. Know that you are not alone in your pursuit and be sure to give a hand up to those who come after you. Good luck!