

# Outcome–Based Science, Technology, Engineering, and Mathematics Education: Innovative Practices

Khairiyah Mohd Yusof  
*Universiti Teknologi Malaysia, Malaysia*

Naziha Ahmad Azli  
*Universiti Teknologi Malaysia, Malaysia*

Azlina Mohd Kosnin  
*Universiti Teknologi Malaysia, Malaysia*

Sharifah Kamilah Syed Yusof  
*Universiti Teknologi Malaysia, Malaysia*

Yudariah Mohammad Yusof  
*Universiti Teknologi Malaysia, Malaysia*

Managing Director:	Lindsay Johnston
Editorial Director:	Joel Gamon
Book Production Manager:	Jennifer Romanchak
Publishing Systems Analyst:	Adrienne Freeland
Assistant Acquisitions Editor:	Kayla Wolfe
Typesetter:	Alyson Zerbe
Cover Design:	Nick Newcomer

Published in the United States of America by  
Information Science Reference (an imprint of IGI Global)  
701 E. Chocolate Avenue  
Hershey PA 17033  
Tel: 717-533-8845  
Fax: 717-533-8661  
E-mail: [cust@igi-global.com](mailto:cust@igi-global.com)  
Web site: <http://www.igi-global.com>

Copyright © 2012 by IGI Global. All rights reserved. No part of this publication may be reproduced, stored or distributed in any form or by any means, electronic or mechanical, including photocopying, without written permission from the publisher. Product or company names used in this set are for identification purposes only. Inclusion of the names of the products or companies does not indicate a claim of ownership by IGI Global of the trademark or registered trademark.

#### Library of Congress Cataloging-in-Publication Data

Outcome-based science, technology, engineering, and mathematics education : innovative practices / Khairiyah Mohd Yusof, Naziha Ahmad Azli, Azlina Mohd Kosnin, Sharifah Kamilah Syed Yusof and Yudariah Mohammad Yusof, editors.

pages cm

Summary: "This book provides insights into initiatives that enhance student learning and contribute to improving the quality of undergraduate STEM education"-- Provided by publisher.

Includes bibliographical references and index.

ISBN 978-1-4666-1809-1 (hardcover) -- ISBN (invalid) 978-1-4666-1810-7 (ebook) -- ISBN (invalid) 978-1-4666-1811-4 (print & perpetual access) 1. Competency-based education. 2. Science--Study and teaching. 3. Technology--Study and teaching. I. Yusof, Khairiyah Mohd, 1965-

Q182.6.O88 2012

507.1--dc23

2012021081

#### British Cataloguing in Publication Data

A Cataloguing in Publication record for this book is available from the British Library.

All work contributed to this book is new, previously-unpublished material. The views expressed in this book are those of the authors, but not necessarily of the publisher.

# Chapter 1

## Aligning Course Content, Assessment, and Delivery: Creating a Context for Outcome-Based Education

**Ruth A. Streveler**  
*Purdue University, USA*

**Karl A. Smith**  
*Purdue University, USA*

**Mary Pilotte**  
*Purdue University, USA*

### ABSTRACT

*The emphasis on Outcome-Based Education (OBE) and student-centered learning is an enormous advance in engineering education. The authors argue in this chapter that an essential element of OBE is aligning content, assessment, and delivery. The objective of this chapter is to provide a model for aligning course content with assessment and delivery that practitioners can use to inform the design or re-design of engineering courses. The purpose of this chapter is to help the reader build a foundation of knowledge, skills, and habits of mind or modes of thinking that facilitate the integration of content (or curriculum), assessment, and delivery (or instruction or pedagogy) for course, or program design. Rather than treat each of these areas separately, the authors strive to help the reader consider all three together in systematic way (Pellegrino, 2006). The approach is essentially an engineering design approach. That is, the chapter starts with requirements or specifications, emphasizes metrics, and then prepares prototypes that meet the requirements. It embraces the argument that “faculty members of the twenty-first-century college or university will find it necessary to set aside their roles as teachers and instead become designers of learning experiences, processes, and environments” (Duderstadt, 2008).*

DOI: 10.4018/978-1-4666-1809-1.ch001

## AN ARGUMENT FOR THE ALIGNMENT OF CONTENT, ASSESSMENT, AND DELIVERY: OVERVIEW AND OBJECTIVE

Our approach is consistent with other initiatives to advance the state of the art of engineering education. The Scholarship of Teaching and Learning (SoTL) is receiving increased attention in higher education and many faculty are embracing more scholarly approaches to teaching and learning. Table 1 (adapted from Streveler, Borrego and Smith, 2007) covers the range of inquiry in engineering education. Levels 1, 2 and 3 were articulated by Hutchings and Shulman (1999). Level 0 was added by Jack Lohmann, and Level 4 was added by Streveler et al. (2007).

We agree with Wankat et al. (2002) and Copola (2011) that engineering faculty should work at Level 2 or above. Faculty practicing at Levels 4 will likely be a small fraction of the entire community; however, faculty practicing at Level 3 could be a large portion of the community. Aligning content with assessment and delivery is consistent with practice at Level 3. A goal of this chapter is to assist faculty in increasing the extent to which they take a scholarly approach to teaching and learning or advance along the levels of inquiry.

Table 1. Levels of inquiry in engineering education

Level	Description
0	Teach Teach as taught, without reflection
1	Effective Teaching Teach using accepted practices
2	Scholarly Teaching Assesses teaching and makes improvements
3	Scholarship of Teaching and Learning Engages in educational experimentation, shares results
4	Engineering Education Research Conducts educational research, publishes in archival journals

We are confident that the alignment of content (or curriculum), assessment, and delivery (or pedagogy or instructional strategy) to design learning modules, courses, and programs is pivotal to advancing the state of the art of practice in engineering education.

Our approach aligns with other models meant to increase innovation in engineering education. Two recent models embrace the cycle of improvement that “closes the loop” between research and practice. Figure 1 for example, was presented at a recent meeting of the US National Science Foundation (Boylan, 2011). Figure 2 comes from the Jamieson and Lohmann (2009) report on engineering education.

The framework we use in this chapter was developed in an engineering education PhD foundation course; Content, Assessment and Pedagogy: An Integrated Engineering Design Approach; that Streveler and Smith teach at Purdue. The chapter is also guided by a faculty workshop, Integrated Course Design for Outcomes Based Education (OBE), that authors Smith and Streveler facilitated for faculty at the Universiti Teknologi Malaysia (UTM) in May 2010.

A principal guide for this chapter is “Creating high-quality learning environments: Guidelines from research on *How People Learn*” (Bransford, Vye & Bateman, 2002). We chose this as our guide

Figure 1. Cyclic model for creating knowledge and improving practices in STEM education (Boylan, 2011)

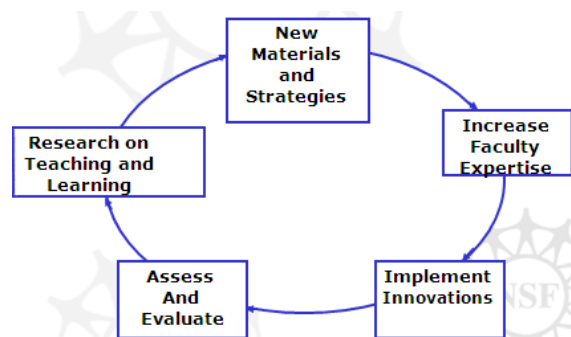


Figure 2. Innovation cycle of educational practice and research (Jamieson and Lohmann, 2009)



Adapted from Booth, Colomb, and Williams, 2008

Engineering education innovation is about designing effective learning environments. It requires, at the least, engineering and education expertise working in continual cycles of educational practice and research.

for three reasons: (1) it was part of a U.S. National Academy of Sciences workshop, (2) it's focused on post-secondary education, and (3) it connects the *How People Learn* framework (Bransford, Brown & Cocking, 2000) to the "Backward Design" approach of Wiggins and McTighe in their book *Understanding by Design* (1998, 2005).

## MODELS OF INTEGRATED COURSE DESIGN

### Models by Felder and Brent, Fink, and Perkins

The idea of a backward-looking design process from student learning outcomes; through acceptable evidence, especially feedback and assessment; to planning instruction has been and is being embraced by others, such as Felder and Brent's (2003) effective course design (Figure 3) and Fink's creating significant learning experiences,

in which he adds emphasis on situational factors that influence the design (Fink, 2003), Figure 4.

A recent and very compelling case for an integrated approach was devised by David Perkins (2009). He described this approach as "learning by wholes" and uses a sports metaphor to elaborate on seven key principles. Perkins offers great insights into designing for integrated learning, such as this gem: "If there's not problem finding in sight, you can be sure that the learners are not playing the whole game." (p. 27).

The key seven principles are:

1. **Play the whole game.** To help students understand the larger context of what they are learning, engage them in some version of the *whole* activity, not just bits and pieces. Perkins calls this kind of activity the "junior game," an activity that allows for an approximation of practice without all the complexity of the real situation. This complexity can often overwhelm novices. Assigning design projects to undergraduate engineering students is an example of creating a "junior game."
2. **Make the activity worth pursuing.** Perkins calls this "making the game worth playing" and it involves practices that help increase students' motivation. Such practice include providing a classroom climate that allows students to feel comfortable going through the trial and error needed for true learning. It also fosters natural curiosity and when appropriate, allows students to make some choices about the topics they will be learning or what order in which they will learn the topics.
3. **Work on the hard parts.** Instructors should reflect on areas they think students will find difficult and develop a "theory of difficulty" which hypothesizes about why some areas are difficult for students. Once areas have been identified the instructor would create exercises that allow students to practice

Figure 3. Effective course design (Felder & Brent, 2003)

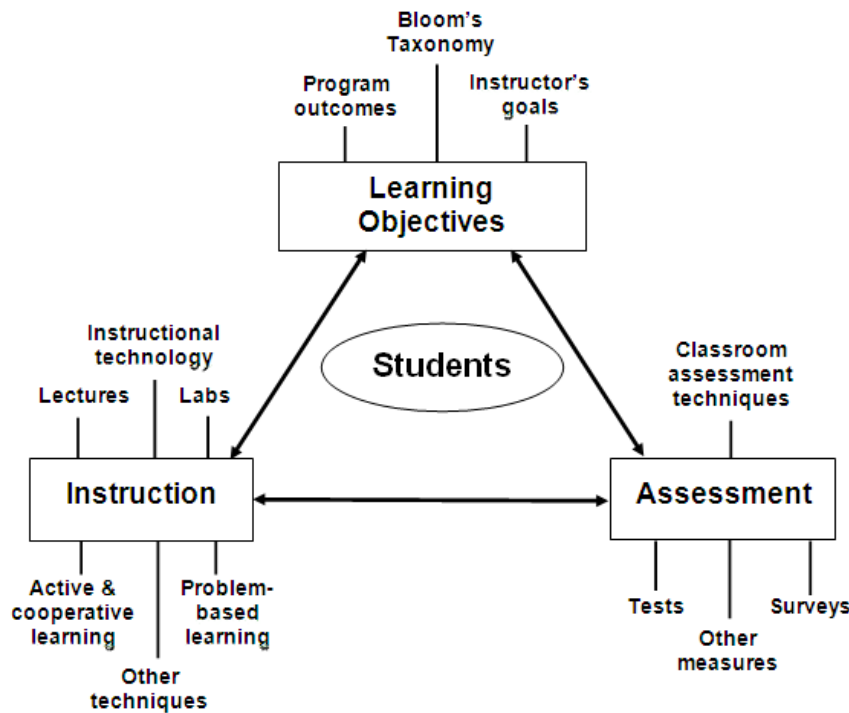


Figure 4. Integrated course design (Fink, 2003)



those difficult parts. Frequent, actionable feedback (feedback that provides direction about what the student can do to correct errors) then allows students to make progress.

4. **Help students apply what they have learned in different settings.** “Transfer” of knowledge to a new area is notoriously difficult to accomplish. Instructors can help students apply knowledge by providing different applications of the target knowledge in different domains. An instructor can also provide opportunities for students to strengthen their conceptual understanding and reflect upon how fundamental knowledge can be used in novel domains.
5. **Make the “unwritten rules” of the discipline explicit for students.** In engineering, this often means expert problem solvers making their thinking approach accessible

through explaining their reasoning to students as they solve problems or think through topics.

6. **Help students learn from each other.** Use cooperative learning approaches and pedagogies of engagement. As noted by Fairweather (2008) there is a large amount of compelling evidence for active student engagement (Astin, 1984, 1993; Light, 1992; Pascarella & Terenzini, 1991, 2005; Kuh, et al., 2005; Kuh, 2008; Johnson, Johnson & Smith, 1991a, 1991b, 1998, 2007; Smith, 2010; Smith, Johnson & Johnson, 1981a, 1981b; Smith, Sheppard, Johnson & Johnson, 2005; Smith, Clarke-Douglas & Cox, 2009).
7. **Foster self-regulated learning in students.** Ask students to reflect on their learning strategies so that they use appropriate methods for understanding, retaining, and applying material they are learning.

An earlier book by Perkins, *Knowledge as Design* (1986) provides a solid foundation for integrated design and structured arguments. We have used it as a text in as one of the texts in our Content, Assessment, and Pedagogy PhD course. As the title of the book implies, Perkins recommends one think of knowledge as design and therefore to “interrogate” the content with questions such as: What its purpose? What is a case model? What is its structure? What is the argument (or the logic behind the knowledge)? Perkins claims that this kind of interrogation allows for much deeper understanding of the target knowledge. This book discusses how to use models and counter-models to assist students’ learning and points out that the salient elements of both models and counter-models needs to be pointed out to students to make the comparison more obvious to them. Perkins also discusses how to use predictions, strategies and even gadgets to help students learn the target material.

## **Wiggins and McTighe’s Understanding by Design (UbD) Model**

*Understanding by Design*, or UbD, is an increasingly popular tool for educational planning focused on teaching for understanding. The emphasis of UbD is on “backward design,” the practice of first looking at the *outcomes* in order to design curriculum units, performance assessments, and classroom instruction. UbD is defined by Wiggins and McTighe as a “framework for designing curriculum units, performance assessments, and instruction that lead your students to deep understanding of the content you teach” (Wiggins & McTighe, 2005).

### **Backward Design Process: Identifying Desired Outcomes**

The first step in the Backward Design Model is identifying what it is you want students to know, to be able to do, and perhaps even to be as a result of the class session, learning module, course, or program. In engineering classes learning outcomes are typically framed as cognitive outcomes, or what we want the students to *know*. We encourage you to consider two additional dimensions of outcomes. What do we want students to be able to *do*? And who do we want the students to *be*? In other words, what are the values and attitudes shared by members of the community that result from our designed learning experience? In his framing document for the *Carnegie Preparation for the Professions Program* Sullivan (2005) describes these three outcome areas as the three apprenticeships – the apprenticeship of the *head* (intellectual development), the *hand* (skill development) and the *heart* (development of habits of mind, values and attitudes).

Wiggins and McTighe (1998) recommend identifying big ideas, topics or processes that (1) have enduring value beyond the classroom, (2) reside at the heart of the discipline, (3) require “un-



coverage” through faculty guidance and insights. Finally, in planning for pedagogies of engagement, Wiggins and McTighe recommend considering to what extent the idea, topic, or process offers potential for engaging students.

We argue that the effective implementation of Outcome-Based Education (OBE) requires thoughtful and purposeful choices of student learning outcomes that are congruent with the key concepts, ideas, procedures, and heuristics associated with the content. Identifying and representing (often with concept maps) the key concepts and the relationships among the concepts that we want our students to master can be extremely difficult (Pace & Middendorf, 2004). And in our experience, most PhD students in our course found it very challenging to articulate and represent the big ideas in the course they were designing.

### Backward Design Process: Assessment

The second step in the UbD model is determining acceptable evidence to decide whether or not, or to what extent, students have met the learning goals. The most important design aspect here is to use criterion-referenced grading system, that is, a mastery model (Bloom, et.al., 1981; Smith, 1996, 1998) such as a point system (i.e. >90% = A) or contract system instead of a norm referenced grading system (grading “on the curve”). Bloom, et al. (1981) made this point as follows:

*If we are effective in our instruction, the distribution of achievement should be very different from the normal curve. In fact, we may even insist that our educational efforts have been unsuccessful to the extent that the distribution of achievement approximates the normal distribution (p. 52).*

Milton, et al. (1986) reiterated this point:

*It is not a symbol of rigor to have grades fall into a ‘normal’ distribution; rather, it is a symbol of failure – failure to teach well, to test well, and to*

*have any influence at all of the intellectual lives of students (p. 225).*

Determining acceptable evidence of achievement is often guided through the use of a taxonomy of student learning outcomes, such as the following:

- **Bloom’s Taxonomy of Educational Objectives:** Cognitive Domain (Bloom & Krathwohl, 1956)
- **A Taxonomy for Learning, Teaching, and Assessing:** A revision of Bloom’s taxonomy of educational objectives (Anderson & Krathwohl, 2001)
- **Facets of Understanding** (Wiggins & McTighe, 1998)
- **Taxonomy of Significant Learning** (Fink, 2003)
- **Evaluating the Quality of Learning:** The SOLO taxonomy (Biggs & Collis, 1982)

Probably the most commonly used taxonomy in engineering programs in the United States is Bloom and Krathwohl (1956); however, for the cognitive domain we prefer Anderson and Krathwohl (2001). See Figure 5.

Content-focused questions typically measure outcomes at the low end of Bloom’s Taxonomy – Remember, Understand – (Anderson and Krathwohl, 2001). To assess students learning outcomes at the middle and upper levels of Bloom’s Taxonomy – Apply, Analyze, Evaluate, Create – open-ended questions and problems are typically used. Recently there is considerable interest in using tasks that approximate practice, and are more authentic and performance-based.

Other taxonomies, such as Wiggins and McTighe (1998) and Fink (2003) include affective outcomes in addition to cognitive and metacognitive outcomes. Figure 6 shows Fink’s (2003) taxonomy.

Assessing students in groups creates additional opportunities and challenges for assessing



Figure 5. Revised Bloom's taxonomy (Anderson & Krathwohl, 2001)

**→ The Cognitive Process Dimension →**

	Remember	Understand	Apply	Analyze	Evaluate	Create
<b>↓ The Knowledge Dimension ↓</b>	<b>Factual Knowledge</b> – The basic elements that students must know to be acquainted with a discipline or solve problems in it. a. Knowledge of terminology b. Knowledge of specific details and elements					
	<b>Conceptual Knowledge</b> – The interrelationships among the basic elements within a larger structure that enable them to function together. a. Knowledge of classifications and categories b. Knowledge of principles and generalizations c. Knowledge of theories, models, and structures					
	<b>Procedural Knowledge</b> – How to do something; methods of inquiry, and criteria for using skills, algorithms, techniques, and methods. a. Knowledge of object-specific skills and algorithms b. Knowledge of object-specific techniques and methods c. Knowledge of criteria for determining when to use appropriate procedures					
	<b>Metacognitive Knowledge</b> – Knowledge of cognition in general as well as awareness and knowledge of one's own cognition. a. Strategic knowledge b. Knowledge about cognitive tasks, including appropriate contextual and conditional knowledge c. Self-knowledge					

student learning. Our recommendation for faculty who use cooperative learning groups is to design, encourage and support students' learning in groups, but assess *individual* learning and performance (Smith, 1998; Johnson & Johnson, 2004).

In addition to the summative assessment of student learning (primarily giving grades as discussed above with regard to the importance of criterion-referenced evaluation), it is also important to provide formative and diagnostic assessment opportunities for students (Angelo & Cross, 1993). More than summative assessments, formative assessments help teachers revise their teaching practices, identify and mitigate potential problems and hindrances to student learning, and

note changes in student learning throughout a course. Related to students, formative assessments help students self-assess their understandings of academic content, support a student-centered approach to learning, and provide an additional method to document this learning (Abbott et al., 1990; Angelo & Cross, 1993; Bransford, et al., 2002). Technology such as wireless classroom communication systems, also has been used extensively in postsecondary settings to increase the amount of formative assessment that occurs within classroom environments (Pea & Gomez, 1992; Dufresne et al., 1996; Mestre et al., 1997; Roselli & Brophy, 2002).

In the absence of technology, instructors may use other classroom assessment techniques to as-

Figure 6. Taxonomy of significant learning (Fink, 2003)

C o g n i t i v e  A f f e c t i v e  M e t a	<b>1. Foundational Knowledge</b>
	<ul style="list-style-type: none"> <li>• "Understand and remember" learning</li> </ul> <p>For example: facts, terms, formulae, concepts, principles, etc.</p>
	<b>2. Application</b>
	<ul style="list-style-type: none"> <li>• Thinking: critical, creative, practical (problem-solving, decision-making)</li> <li>• Other skills</li> </ul> <p>For example: communication, technology, foreign language</p> <ul style="list-style-type: none"> <li>• Managing complex projects</li> </ul>
	<b>3. Integration</b>
	<ul style="list-style-type: none"> <li>• Making "connections" (i.e., finding similarities or interactions) . . .</li> </ul> <p>Among: ideas, subjects, people</p>
	<b>4. Human Dimensions</b>
	<ul style="list-style-type: none"> <li>• Learning about and changing one's SELF</li> <li>• Understanding and interacting with OTHERS</li> </ul>
	<b>5. Caring</b>
	<ul style="list-style-type: none"> <li>• Identifying/changing one's feelings, interests, values</li> </ul>
	<b>6. Learning How to Learn</b>
	<ul style="list-style-type: none"> <li>• Becoming a better student</li> <li>• Learning how to ask and answer questions</li> <li>• Becoming a self-directed learner</li> </ul>

sess students formatively (Angelo & Cross, 1993). For example, the “Minute Paper” technique asks students to give a two- to three-minute response on index cards about what they are learning in the class and what questions remains unanswered. Similar to the “Minute Paper,” the “Muddiest Point” gives an instructor quick feedback about students’ understanding. With the “Muddiest Point,” students are asked to identify the most confusing or most difficult aspect of a lesson. Instructors may use additional formative techniques depending upon the information that they want to obtain from their students.

Here is an example of a “Minute Paper” from one of Karl Smith’s courses. The formative assessment (Figure 7) was administered at the end

of the first class session and the feedback (Figure 8) was presented and discussed at the beginning of the second session of a semester-long course.

The quantitative aspect of the assessment addresses areas that Smith has identified as potential concern areas for the students – (1) the pace (some think it’s too fast, some too slow), (2) the relevance (Smith is deeply concerned that the students getting something useful out of the course), and (3) the format (the course employs a highly student-student interactive format that not all students like). Students’ responses to the first three short-answer questions are typically very interesting and provide excellent insight; however, they are more difficult to summarize and report.

Figure 7. Classroom assessment sample questions

Session Summary  
(Minute Paper)

Reflect on the session:

1. Most interesting, valuable, useful thing you learned.
2. Things that helped you learn.
3. Comments, suggestions, etc
4. Pace: Too slow 1 . . . . 5 Too fast
5. Relevance: Little 1 . . . 5 Lots
6. Instructional Format: Ugh 1 . . . 5 Ah

Backward Design Process:  
Plan Instruction

The third step in the backward design process is planning instruction. We focus on pedagogies of engagement – cooperative learning, problem-based and project-based learning, inquiry guided

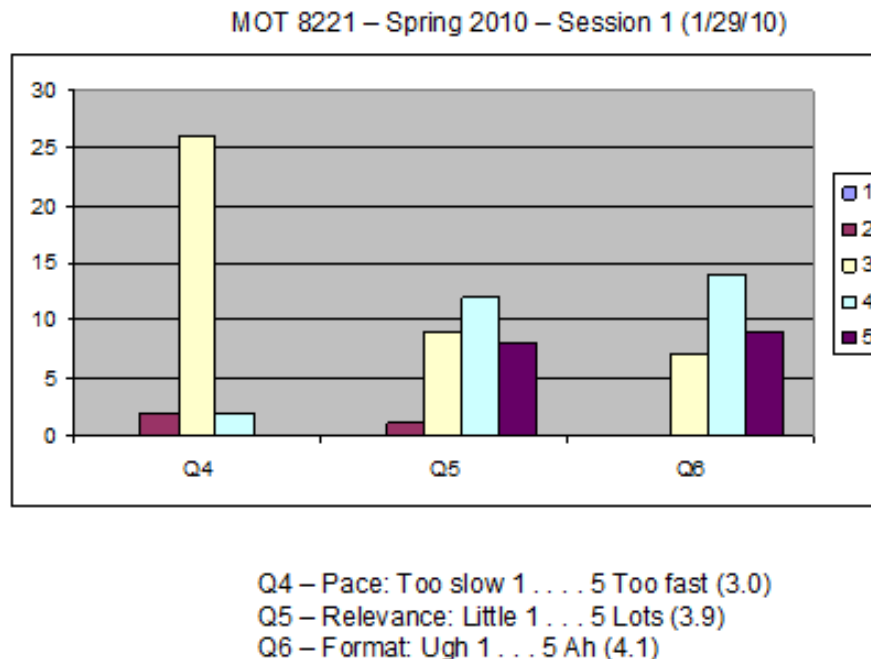
learning – for learning outcomes that represent big ideas, are at the heart of the discipline, require un-coverage, and have potential for engaging students.

**TOOLS FOR ALIGNING CONTENT,  
ASSESSMENT, AND DELIVERY**

We argue that an important part of the integration of content, assessment and delivery is the accomplished through knowing about appropriate educational theory. It is important to anchor the work in learning theory, assessment theory and instructional theory.

Another place to start is to examine one's theory of student learning. How one views learning has profound implications for the design of instruction (Svinicki, 1999). Those who view learning as a matter of stimulus-response (i.e. a behaviorist view) will design instruction that provides a time for a lot of practice with immediate rewards or punishment. This will lead to instructional settings

Figure 8. Classroom assessment sample results



with many repetitive exercises that are quickly assessed with points for successful completion given as rewards. Others who see learning as a cognitive activity will focus on what is happening in an individual student's brain and would create opportunities for students to link prior knowledge to what they are learning. Proponents of social cognitive learning theory will describe learning as a process that is constructed socially. This point-of-view would imply that groups or teams of students be given the opportunity to learn together through joint exercises or projects.

When explaining tools for alignment we will both describe the process generally as well as provide an example of how these methods were used in one curriculum project. The example curriculum project involved development of an on-line course called *Entrepreneurship for Engineers*, designed by author Pillotte for engineering students interested in exploring topics of entrepreneurship. *Entrepreneurship for Engineers* was designed in response to entrepreneurship studies becoming an increasingly sought after collegiate level educational programs (Charney & Libecap, 2003). The on-line component of the course interjected both intrigue and challenges associated with teaching and learning in an increasingly popular virtual setting.

## **Tools for Aligning Content**

Alignment both within and between course elements is the major theme of this approach to curriculum design. Therefore it is vital to have tools that help to increase alignment. This section discusses tools that assist instructors in aligning the content of the instructional unit.

## **Curricular Priorities**

Wiggins and McTighe recommend that the design of instruction begin with identification of three areas of content. First they call the curricular priorities: areas that are enduring understanding,

important to know, and worth being familiar with. As will be discussed in more detail later, Figure 9 provides an example of how these curricular priorities were mapped in *Entrepreneurship for Engineers*.

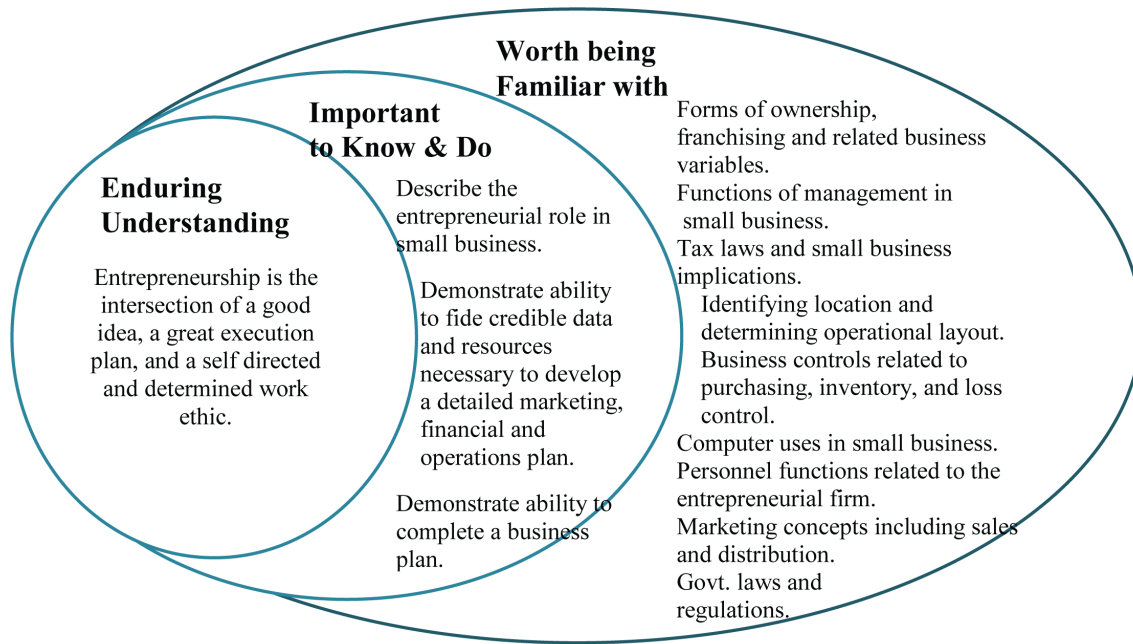
When establishing curricular priorities one first should identify what is the enduring understanding the students should take away from the course. These are areas that reside within the heart of the discipline. They are the kind of things that students will retain long after instruction is over. For example, in engineering instructors often say that they want engineering graduates to have a particular style of problem solving or the ability to learn on one's own. These types of things would be listed as being part of the enduring understanding. Determining the enduring understanding of the content one plans to teach is a critical first step in the curriculum development process as many other design decisions in the depend upon the enduring understanding.

In addition to enduring understanding, Wiggins and McTighe recommend that instructors also identify areas that are important to know and do. For example, the ability to perform a particular kind of analysis may be something that is important to know.

And finally, the third classification is things that are worth being familiar with. This category may include techniques or terms that would be beneficial for students to know although they do not reside at the heart of the discipline.

Engaging in developing curricular priorities can help the instructor think deeply about the content – particularly in identifying the true intended outcomes of the instruction. This provides a pointer to the instructor – reminding him or her to explicitly focus on areas of high importance. Even an experienced instructor may be caught in the trap of placing too much emphasis on things that are “worth being familiar with” while ignoring what lies at the heart of the discipline – hoping students will just “pick up” the really important things by practicing the less important things.

Figure 9. Enduring understanding diagram for Entrepreneurship for Engineers



In the *Entrepreneurship for Engineers* example, author Pilotte proposed that the enduring understanding for students was a clearer perspective on what it takes to migrate from having a great idea, to becoming an independent small business owner, in the full entrepreneurial sense. (See Figure 9).

### Enduring Understanding

In particular, the hope in *Entrepreneurship for Engineers* is that students come to appreciate how a well thought out plan can lead to a successful business endeavor, while also realizing how it demands a self-determined personal work ethic, and a purposeful approach to see an idea become a reality. This notion of enduring understanding was developed after long consideration of what many successful entrepreneurs report regarding their personal demonstrated success. For example, few entrepreneurs would claim that it was their exceptional tactical understanding of business controls that made them successful, but many report

that their success came generating an innovative idea, carefully nurturing that idea with a plan to launch, and a lot of hard work. Upon reflection, it seemed these few but critical considerations must lead any tactical or technical curricular priorities, if the true objective of the course was to generate entrepreneurial successes. For your course enduring understanding, consider what the strategic “big idea” is, that you want your students to leave the course with.

### Important to Know

Other important to know elements proposed for the course include having students depart with an improved perspective of the entrepreneur’s role in small business development. This includes aiding students in making connections between how the idea developed by an entrepreneur can translate into either a full business plan for execution, or into intellectual property for sale or further self development. Additional important to know topics might include learning where and how to

collect important business intelligence necessary to create a business plan, as well as the essential elements for producing a viable business plan. These important to know themes advance the enduring understanding into more actionable concepts, moving the student thinking from a high conceptual theme, onto a more action oriented set of ideals and roles.

Upon reflection, author Pilotte reports that the difficulty in determining the few key important to know themes, revolves around the fact that few text books are structured to focus on a few high level themes, rather they tend to be exhaustive in their inclusion of all possible related content. The implication for this comprehensive approach seems to infer that conducting a course that falls short of complete inclusiveness is somehow short-changing the student learning experience, or not properly serving the content domain. While it is possible to teach an entire text book from cover to cover, the practicality of prioritizing what is truly important for your students must prevail. The question one might ask themselves when determining important to know items is, “what are the few critical actions or understandings – at a tactical level, that my students must take with them from the class?”

### **Worth Being Familiar With**

In *Entrepreneurship for Engineers*, other more tactically oriented topics are proposed for students to become familiar with, with lower curricular priority including more functionally oriented areas of the business operation and management. Choosing content for this section was done so with an eye towards minimizing the negative implications of not knowing about a certain topic, rather than maximizing the upside of being a subject matter expert on the topic. With that in mind, choices might include aspects of managing a small business to understanding and determining ideal forms of ownership and government laws and regulations. The intent of content chosen here is by no means

intended to convert an engineer into a lawyer or regulatory compliance officer. Rather it is intended to highlight the importance of considering such business aspects so that the student might give consideration to them as they develop their ultimate deliverable, the business plan.

### **Concept Maps**

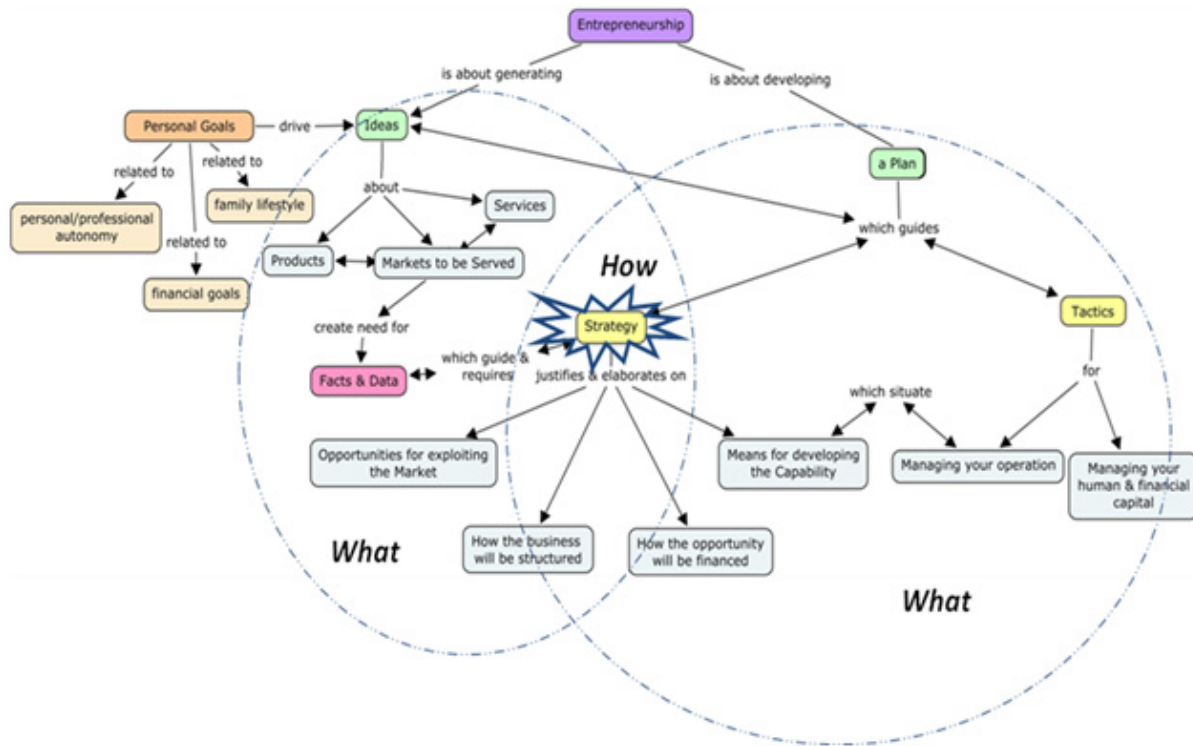
Concept mapping is another tool that may be used to align content. A concept map is a way of graphically organizing content. Concept maps have been used in education for decades (Buzan, 1991) and have been popularized in academia through the work of Novak & Gowin (1984). There are a variety of methods for creating concept maps but most include a graphics that are linked together to show hierarchical and inter-element relationships.

Creating concept maps fosters instructors’ thinking about the relationship of concepts and topics within an instructional unit. This information is useful for the instructor but is also very important for students. Sharing a class concept map with students reveals course organization to them, and can be a powerful tool for memory as well as understanding. Concept maps are another way of checking alignment because one should see that the enduring understandings are the foundational elements of the concept map, with areas important to know or worth being familiar with taking a supporting role at the periphery of the map. For example, in Figure 10, one can see that the enduring understanding of this course, that ‘entrepreneurship is the intersection of a good idea, a great execution plan,’ lies at the center of the concept map. The concept map and curricular priorities are often iteratively planned, as development of one informs the development of the other. If one’s concept map does not reflect one’s curricular priorities one knows that more thinking needs to be done about the curriculum design.

The power of creating the concept map for curriculum developers is the value of consideration and clarity that comes with creating iterations of



Figure 10. Concept map for Entrepreneurship for Engineers



the concept map. For author Pilotte, no less than three concept maps were created before arriving at one that truly displayed not only the relationship between topics, but also most accurately depicted the hierarchical value of the enduring understanding diagram.

Figures 11 and 12 represent a first and iterative draft of the *Entrepreneurship for Engineers* course concept map. Even without reading the words, one will notice that the first draft version (Figure 11) is extremely linear in nature; one directly flowing to another, with no display of interconnectedness of themes or circular flows indicating some form of iterative understanding. Close examination Figure 11 also breaks down the course into very vertical “silo topics,” driven primarily by how the traditional textbook for this topic is structured to teach the material (i.e. product/service, mission, human resources, etc.).

Figure 12, a “midstream” concept map, begins to show how the vision of the course is taking form around the notion of enduring understandings for course; the idea and the plan well executed through strategy and tactics, but still falls short in demonstrating how the individual’s personal motivation plays a role. In Figure 13 the lines, while still shown in linear form, have begun to display a more interrelated and iterative view of the course topics and has evolved somewhat from a rigid hierarchical or content view.

The “final” concept map (Figures 10 and 13) is author Pilotte’s best attempt, after nearly eight weeks of development, at depicting the enduring understanding and other curricular priorities while taking into consideration the very interrelated and cross-disciplinary nature of content, examples, strategies and execution plans. The content is driven from two main themes of “what is entre-



Figure 11. First draft concept map

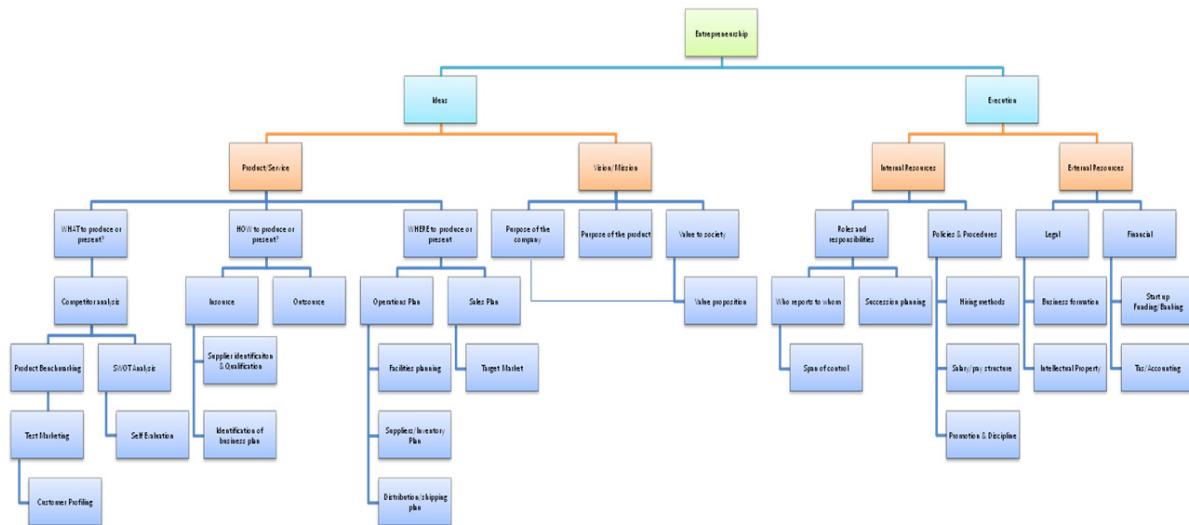
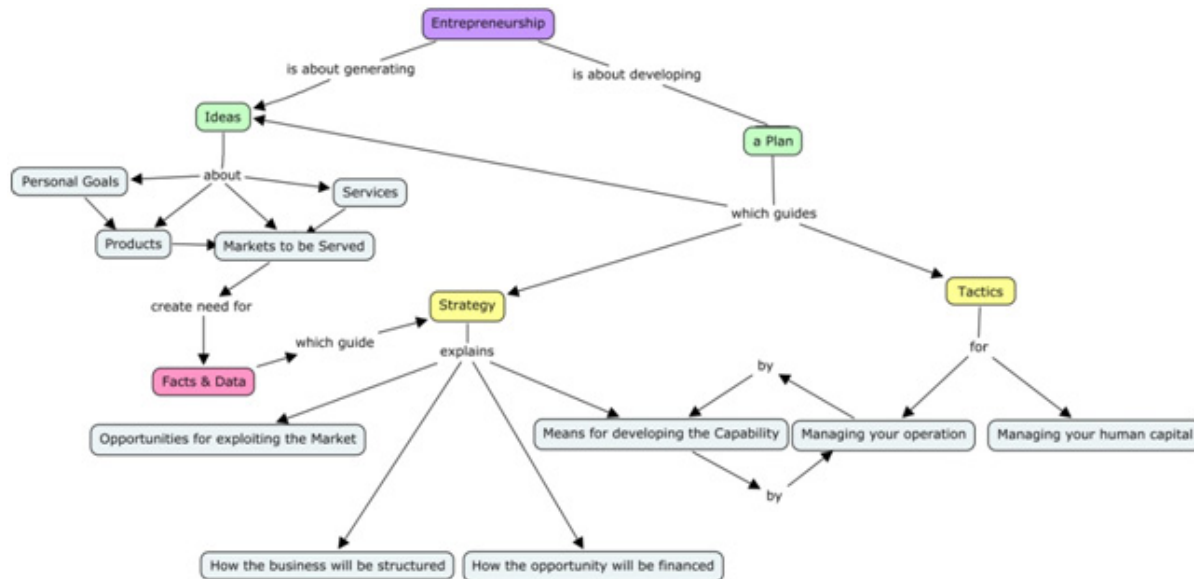


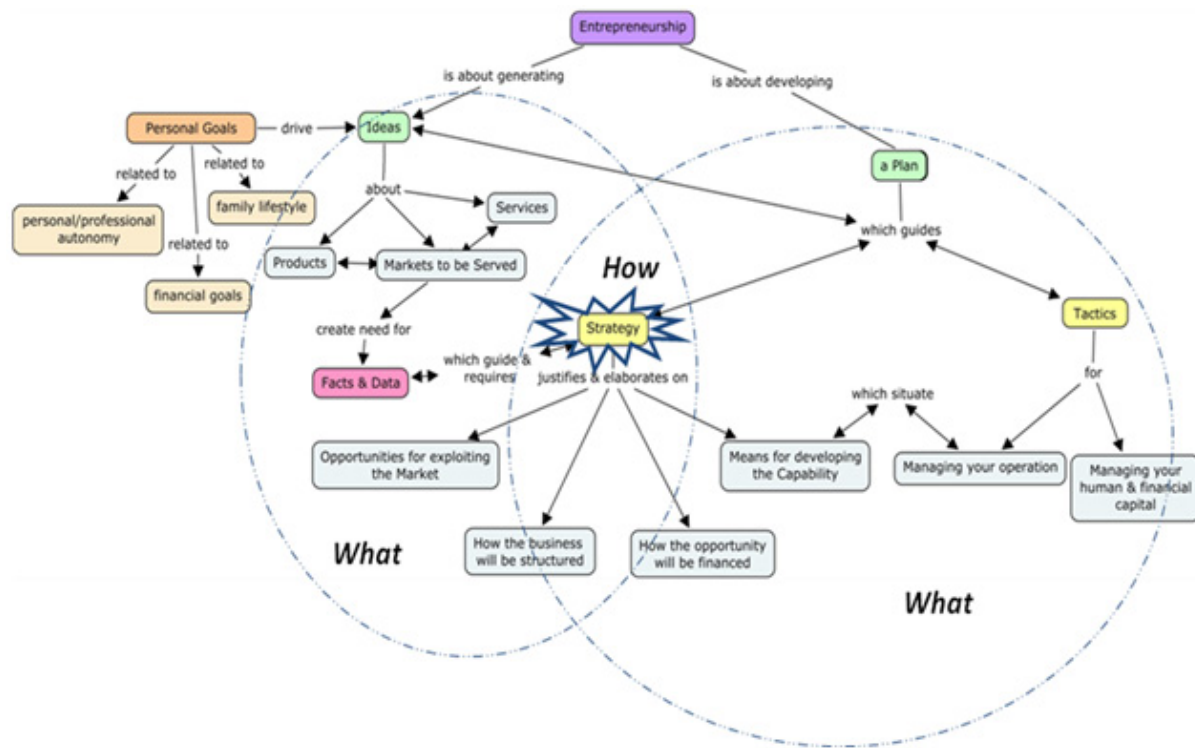
Figure 12. Second iteration of concept map



preneurship”: an idea (innovation) and a plan (execution). It then links these two content themes together through content on strategy that discusses they “how to execute your entrepreneurial concept,” while encouraging the students to consider the “why this idea should be executed” on a personal level.

Course content focused at the university level exclusively on what to know, has left students discouraged about the proposition of entrepreneurship, (Gorman, Hanlon, & King, 1997). It would seem that most entrepreneurship courses tend to focus on *what to know* rather than educating students on more subtle topics like *when to act*

Figure 13. “Final” concept map



on an idea (use of intuition), understanding *how* to execute (practical tactical skills), and comprehending *why* elements of entrepreneurship should be considered a certain way (personal goals/motives and values) (Béchar & Toulouse, 1997). The goal of the *Entrepreneurship for Engineers* is to turn past instructional practice on its head, and serve up the “whys & hows” first, allowing the “what” to take on a more secondary role. This final vision of the course also maps well to the three apprenticeships - of head, hand and heart (Sullivan, 2005) - mentioned previously.

## Tools for Aligning Assessment

Writing learning goals is the activity that links content with assessment. Learning goals should be written so that they reflect curricular priorities. In other words, an instructor will want to be sure

write learning goals that point to enduring understandings, topics that are important to know, and areas worth being familiar with. Learning goals written around areas of enduring understanding should be considered the highest priorities learning goals for the curricular unit one is designing.

It is good practice to map learning goals to a taxonomy of learning such as the SOLO taxonomy (Biggs and Collins, 1982) or those authored by Bloom and Krathwohl (1956), Anderson and Krathwohl (2001), or Fink (2003). By mapping the learning goals to a taxonomy, we mean checking the level of the learning goal within the chosen taxonomy and making sure that level is appropriate for the kind of learning one wishes to foster.

These two activities will now be illustrated using the *Entrepreneurship for Engineers* as an example.

## Write Learning Objectives Aligned with Curricular Priorities

Evaluating student development in terms of enduring understanding can be achieved by measuring the extent to which individual learning objectives are being satisfied. In *Entrepreneurship for Engineers*, students were expected to successfully complete the following course learning objectives:

1. **Identify the key characteristics** of an entrepreneur.
2. **Identify the self-directed work habits and positive attributes** frequently found in successful entrepreneurs.
3. **Explain the value** of developing self-directed work habits and positive attributes frequently found in successful entrepreneurs.
4. Exercise basic primary and secondary research skills, necessary to **locate and acquire credible industry/task specific information** necessary to support each section within a standard business plan template.
5. **Synthesize relevant facts and information** to develop a complete written business plan for their desired business.
6. **Participate in an entrepreneurship community of student learners**, using the distance learning (DL) on-line course tools, discussion board forums, etc.

The first three objectives focused on building foundational knowledge, by providing simple facts about entrepreneur's common characteristics, work habits and attributes common to entrepreneurs, and the value associated with such attributes. It is these three course learning objectives that tie directly to the enduring understanding for the course.

While at first glance this information may seem too basic, it is just such basics-building that is encouraged in Bruner's Constructivist Theory (Bruner, 1966). By providing a sequence of spe-

cific learning objectives that build upon each other, students can begin to "construct" their understanding of what being an entrepreneur is all about. The objectives also help students test notions they entered the class with, and build new structures of more complex understanding around the topic of entrepreneurship and small business ownership.

We next examine the fourth and fifth course objectives: locate information and synthesize to complete a written business plan. These objectives leverage the kinds of interactive learning that aligns with the curricular priorities of the important to know and do section.

These learning objectives also begin to transition students to higher order learning and deliverables offering more tangible assessment. Learning objective number 5 migrates participants from students of entrepreneurship, to contributors of entrepreneurial thinking. It helps take the tactical skills and activity to a level of strategic consideration. This is important as students begin to more fully consider if the idea they brought to class is a viable business idea – or just an idea too far ahead, behind, or difficult for its time.

Finally, learning objective number six situates students with an opportunity to practice the attributes of earlier learning objectives, by engaging them in a more social learning environment. Set in the context of an on-line learning, the *Entrepreneurship for Engineers* course encourages students to take control of their own learning to an extent, just as they would in the "real world" of entrepreneurial endeavors.

## Mapping Learning Goals to a Taxonomy

How do learning goals fit within a taxonomy, for example Bloom, revised Bloom, Fink, or SOLO? Table 2 follows showing how the learning goals are placed within a taxonomy - in this case, Fink's. (For a review of Fink's taxonomy, see Figure 6.) Taxonomies can assist in helping to determine the

appropriateness of learning objectives for course designs. Author Pilotte chose to utilize Fink's taxonomy, based on the its cross domain view of developing and reviewing learning objectives and a perceived emphasis on entrepreneurial learning

attributes including those associated with the application of learning, integration of learning and self learning. Further, Fink's taxonomy rejected the rigid hierarchical structure of other taxonomies that promote mastery of lower level content be-

*Table 2. Development worksheet for the Entrepreneurship for Engineers course*

Kinds of Learning	Objective #1 2, & 3 Identify & Explain the Value of Developing Self-Directed Work Habits	Objective #4 & 5 Locate & Synthesize Info to develop and complete a written Business Plan
<b>Questions supporting the course learning objectives</b>		
<b>1. Foundational Knowledge</b>	<ul style="list-style-type: none"> <li>• What are the personal and behavioral attributes on an entrepreneur?</li> <li>• How are such attributes and ethics developed?</li> <li>• How do those attributes display themselves in entrepreneurial settings?</li> <li>• Can you learn to be entrepreneurial?</li> </ul>	<ul style="list-style-type: none"> <li>• What does a business plan template look like and what do they consist of?</li> <li>• What are the types of data/information required to build a business plan?</li> <li>• Where can such data/information be found?</li> <li>• What role does trade associations play in providing valuable business plan data/information?</li> <li>• What role does local economic development corporations play in providing data/information?</li> </ul>
<b>2. Application</b>		<ul style="list-style-type: none"> <li>• How do you determine the validity, credibility, and usefulness of data/information you find?</li> <li>• How do you develop and substantiate your own unique estimates?</li> <li>• How do you prioritize the importance of the data you choose to use when synthesizing all that has been located?</li> <li>• How do you present/relay the data and information in a way they become compelling to the target audience?</li> <li>• How can you demonstrate that your prototype business idea is unique and desired by creating new data, artwork, information that could be incorporated into the business plan?</li> </ul> <p>Skills include...</p> <ul style="list-style-type: none"> <li>• Library research skills</li> <li>• Basic budget development skills</li> <li>• How to present an idea for the purpose of "selling the target audience".</li> <li>• Clear and succinct business writing skills. Basic planning skills including a focus on the future and with an eye towards cause and effect, as well as an ability to develop a simple 5 year financial plan.</li> </ul>
<b>3. Integration</b>		<ul style="list-style-type: none"> <li>• How does the data/information gathered regarding competitive products/services impact your approach to entering the market?</li> <li>• How does the data/information gathered on the target market impact how you would propose producing, promoting and distributing the product?</li> <li>• How does the data/information gathered on the size of the target market affect the operating budget and the 5-year financial plan?</li> <li>• How does the operational plan impact data/information gathered regarding growth in the industry?</li> </ul> <p>Etc...</p>

*continued on following page*

Table 2. Continued

Kinds of Learning	Objective #1 2, & 3 Identify & Explain the Value of Developing Self-Directed Work Habits	Objective #4 & 5 Locate & Synthesize Info to develop and complete a written Business Plan
Questions supporting the course learning objectives		
<b>4. Human Dimension</b>	<ul style="list-style-type: none"> <li>• Without the traditional lecture/assignment environment – which requires weekly face-to-face accountability for deliverables, are you able to manage time effectively to still deliver your assignments on time? How does developing strong time management skills as a student translate to being a more effective entrepreneur?</li> <li>• Have you been self-motivated to the point you have frequently accessed the required class materials being presented to on-line locations? What impact might this level of motivation have on the success of your business idea?</li> <li>• Entrepreneurship requires becoming an expert on many aspects that surround the development of an idea/service/product. Have you enjoyed learning about the other aspects of entrepreneurship?</li> <li>• Have you found the process of “self educating” on the topics interesting or laborious?</li> <li>• Some people are planners, some people are executors; entrepreneurs are a mix of both in many ways. How do you view yourself? Etc...</li> </ul>	<ul style="list-style-type: none"> <li>• Based on the data and information you have collected about your ideas, service or market – do you feel there remains a viable business opportunity worth pursuing based on your interests and capabilities?</li> <li>• Do you feel you have the personal drive and stamina to execute the business plan as developed, given the facts and information about the market conditions, competition, investment requirements, etc?</li> <li>• As the information you have acquired comes together to form the business plan, is this a company and plan you could still feel excited about launching, owning and operating?</li> </ul>
<b>5. Caring</b>	Values of an entrepreneur... <ul style="list-style-type: none"> <li>• Natural curiosity for learning how to make a business run.</li> <li>• A desire to see an idea born.</li> <li>• An appreciation for the knowledge held by subject matter experts.</li> <li>• An appreciation for the family sacrifices associated with entrepreneurship.</li> </ul>	
<b>6. Learning How to Learn</b>	<ul style="list-style-type: none"> <li>• DL courses require personal discipline for completing research without much direct guidance.</li> <li>• Information regarding ideas on products/services/operations can be found from a wide variety of places and venues.</li> <li>• How to take a large project, break it down into smaller pieces so that it becomes manageable small weekly bites to complete.</li> </ul>	

fore advancing to content deemed higher level, a concept that didn't seem to be congruent with the dynamic content associated with entrepreneurship, that sometimes moved between “upper and lower level content” by necessity.

Table 2 for *Entrepreneurship for Engineers* was developed by systematically taking each learning objective, and questioning how that objective advances significant learning along

Fink's six prescribed dimensions of foundational knowledge, application, integration caring, human dimension, and learning how to learn.

Pilotte found that mapping each learning objective with Fink's taxonomy was extremely valuable in directing the course content outline, and helping her to focus on key issues that would drive the type of learning required to successfully navigate students through the course.

Not only does this mapping exercise force the consideration of importance for each learning objective, the resulting table can be used as fodder for guiding student discussion about why specific content might be viewed as important for their overall learning.

After a course designer has worked through the content to be presented, it is necessary to align the assessment with the content. One must be sure that the most important topics are the concepts that are actually assessed. If some topics are truly at the heart of the discipline (in the “enduring understanding” category) one wants to make sure that these vital understandings are assessed.

### Assessment Worksheet

Misalignment of curricular priorities with assessment is all too common. Perhaps we have all experienced assessments that seemed to focus on the small details of an area that were not stressed as being important. This is an example of misalignment of content and assessment and the instances of this are as common as they are painful to the students.

Luckily there are tools available to alignment content and assessment. One very important tool

called the “assessment worksheet” (Table 3), was developed by the first apprentice faculty in the Content, Assessment and Pedagogy class, Shanna Daly (2008). Wiggins and McTighe (1998) and Pellegrino et al. (2001) were Daly’s inspiration for the worksheet, which she created as way to depict the important points of those readings.

The assessment workshop provides a structure for being sure assessment is aligned. As seen in Table 3, using learning objective 4 for *Entrepreneurship for Engineers* as an example, the assessment worksheet aligns learning goals and assessment, thus ensuring a link between content and assessment.

The *Entrepreneurship for Engineers* learning goal in this example, focuses on helping students develop basic research skills with credible sources, such that they can begin to amass a library of reference material to support and build their business plan. From this objective, a claim statement must be developed. This particular assessment was seen as a type of formative assessment.

Next, the specific task was developed; the student would respond to questions on their electronic discussion board related to the business plan section being taught. This task not only allowed students to put their research ideas out before

*Table 3. Assessment worksheet for Entrepreneurship for Engineers*

Learning Goals and Assessments	
Learning Goal #4	Assessment
Students will be able to exercise basic primary and secondary research skills, necessary to locate and acquire credible industry/task-specific information necessary to support each section within a standard business plan template.	<b>General:</b> Written formative assessment
	<b>Claim:</b> Students will be able to locate facts and information relative to their business proposals through the use of the “V-Cat” internet library, physical library, local SBA and other small business contacts and resources.
	<b>Task:</b> Given questions via the e-discussion board, students will respond to these weekly discussion board questions focused on providing information gathered which is related to the specific section of the business plan presented in that week’s readings and e-lecture.
	<b>Evidence:</b> Students will respond to the weekly e-discussion board within the prescribed time frame, with a written response. The student response will include a description of the facts and information they find important toward the specified section of the business plan, why they feel this information is relevant and contributes towards their business plan section, and the reference location and complete citation from which they collected the information.



their instructor for assessment, but also out before their entrepreneurial peers, advancing learning objective 6 at the same time. It further positioned them to begin to review other students' postings and compare their submittals to those of other students on line at the same time. In this example, the students practiced writing about their research activity by writing on the discussion board. And the responses also gave the instructor a view to the students' level of absorption and understanding.

The individual student postings become the material of assessment related to the learning objective, while the evidence block noted above is the approach for determining how well the student met the learning objective. In our example, the instructor would evaluate the posting to see if the response was fact based, supported with a professional reference. In addition they would assess if the information was relevant to the section being covered, and if the student had engaged in self reflection as to why this material might be appropriate in relation to their proposed business idea.

## **Assessment Triangle**

A second method for aligning assessment with content is called the assessment triangle and is explained in the book, *Knowing What Students Know* (Pellegrino et al, 2001). When creating any assessment three areas should be aligned - cognition, observation, and interpretation. The assessment triangle is a method of representing this alignment. The "cognition" corner of the triangle refers to one's theory about how students learn the content in the target domain. This would include areas where students have been observed to have difficulty, as well as any information in the literature about pre-conceptions or misconceptions documented by researchers. The cognition corner could also include ideas about what characteristics exemplify the progression of proficiency from novice to expert. Said in a simpler way, this

refers to characteristics one will look for to know students' performance is improving in a domain.

The information about student learning in the target domain (cognition corner) then guides one's thinking about what kind of tasks one should present to the students to assess their knowledge. The "observation" corner describes the actual assessment task itself. What will be "observed" to determine if the skill, knowledge, or attitude is possessed by the student? Finally, the "interpretation" corner of the assessment triangle refers to the methods used to analyze the data collected during the "observation" or assessment. Assessment data should be interpreted in a way that is warranted by the task (observation corner) and makes sense with regards to how students learn in the targeted domain (cognition corner). Thus all three corners need to be consistent with one another.

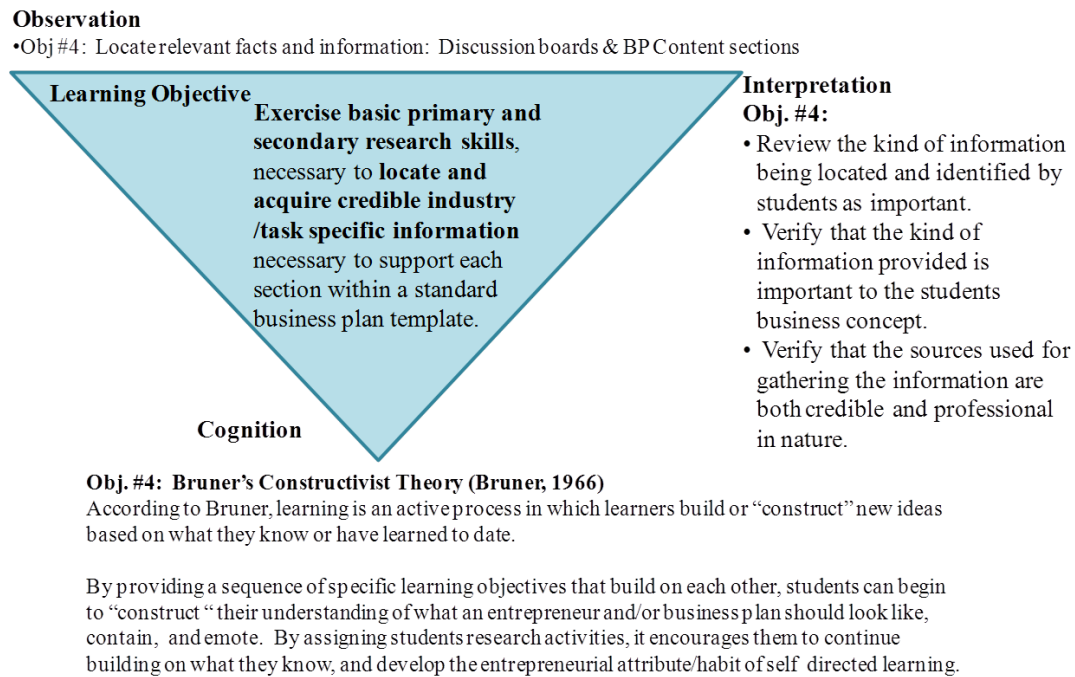
As we did with the assessment worksheet, we use learning objective 4 of *Entrepreneurship for Engineers* to illustrate the assessment triangle (see Figure 14).

In the *Entrepreneurship for Engineers* example, the assessment for learning objective four is evaluated through the lens of the cognition corner that includes Bruner's Constructivist Theory (Bruner, 1966). This theory proposes that learners develop or build new ideas based on what they already know, and by creating a careful series of learning objectives that gradually build on each other, you can "construct" a complete understanding for a given topic.

If we assume that students self select entrepreneurship based on some past experience or set of ideas, and that they build on and, where necessary, reform those ideas then Bruner's theory seems to be an appropriate cognitive platform on which to assessments. Under the observation corner, students create discussion board entries based on their research activities. These entries then become the observable items for assessment. These discussions would not only include their newly discovered research, but they would be



Figure 14. Assessment triangle for Entrepreneurship for Engineers



asked to discuss why they felt the research was appropriate for the discussion question, causing them to draw upon on their own understanding of the topic at hand, and integrate the new ideas they have acquired through this learning activity.

Finally, the interpretation corner for the target learning objective informs the course designer how the observed component (the discussion board entry) of the learning objective will be assessed. Questions for assessment include: Did the student locate the appropriate kind of information to support the question? Does the information provided support the student’s business concept? Were the sources of information credible? These questions should align directly with the evidence block of the assessment worksheet.

### Tools for Aligning Delivery: Course Development Worksheet

Dee Fink (Fink, 2003) developed the worksheet seen in Figure 15. The beauty of this worksheet is that the three parallel columns (learning goals, ways of assessing, and actual teaching-learning activities) remind the course developer these three elements should be consistent. In other words, important learning goals should be the things that are assessed and teaching-learning activities should logically follow from these. Table 2 shows how this worksheet was used in *Entrepreneurship for Engineers*. By making sure that learning activities (Column 3) are closely aligned with learning goals (Column 1) and assessment measures (Column 2) the content-assessment-delivery cycle is complete.

Figure 15. Course development worksheet

Learning Goals	Assessing this Learning	Learning Activities	Helpful Resources: (e.g., people, things)
1.			
2.			
3.			
4.			
5.			
6.			

## CONCLUSION AND NEXT STEPS

Engineers frequently argue that design is the essence of engineering and therefore a design approach for courses is most consistent with the engineering method. For example, the consensus in a 1986 National Science Foundation Workshop was:

*Design in a major sense is the essence of engineering; it begins with the identification of a need and ends with a product or system in the hands of a user. It is primarily concerned with synthesis rather than the analysis which is central to engineering science. Design, above all else, distinguishes engineering from science.*

Design involves progressive refinement, typically through iteration (Koen, 2003, 2009) working

within constraints (Wulf, 1998) and coping with uncertainty and using judgment (Goldman, 2004), and many other contingencies. Our experience with four iterations of the CAP course at Purdue brought us face-to-face with these challenges as well as many others. The students in our CAP course had difficulty (1) identifying the student learning outcomes that merit “enduring understanding,” (2) mapping the relationships among the concepts in their course, and (3) aligning content, assessment and pedagogy; however after struggling with challenges in the emerging Community of Practice of participants in the course, produced thoughtful and well-articulated designs. Just as our students have done, we hope that readers of this chapter will use the tools and examples provided herein to create high-quality, outcome based curriculum.

## REFERENCES

- Abbott, D., Broadfoot, P., Croll, P., Osborn, M., & Pollard, A. (1994). Some sink, some float: National curriculum assessment and accountability. *British Educational Research Journal*, 20, 155–174. doi:10.1080/0141192940200202
- Anderson, L. W., & Krathwohl, D. R. (Eds.). (2001). *A taxonomy for learning, teaching, and assessing: Revision of Bloom's taxonomy of education objectives*. New York, NY: Addison Wesley.
- Angelo, T. A., & Cross, K. P. (1993). *Classroom assessment techniques: A handbook for college teachers*. San Francisco, CA: Jossey-Bass.
- Astin, A. W. (1984). Student involvement: A developmental theory for higher education. *Journal of College Student Personnel*, 25, 297–308.
- Astin, A. W. (1993). *What matters in college? Four critical years revisited*. San Francisco, CA: Jossey-Bass.
- Béchar, J. P., & Toulouse, J. M. (1997). *Theorizing on entrepreneurship and education: Proposition of an integrative model*. Paper presented at the 7th Global Entrepreneurship Research Conference Montreal Canada.
- Biggs, J. B., & Collins, K. F. (1982). *Evaluating the quality of learning: The SOLO taxonomy*. New York, NY: Academic Press.
- Bloom, B. S., Engelhart, M. D., Furst, E. J., Hill, W. H., & Krathwohl, D. R. (1956). *Taxonomy of educational objectives: The classification of educational goals: Handbook I: Cognitive domain*. New York, NY: Longmans.
- Bloom, B. S., Madaus, G. F., & Hastings, J. T. (1981). *Evaluation to improve learning*. New York, NY: McGraw-Hill.
- Boylan, M. (2011). The federal environment for STEM education programs: Implications for TUES. Presentation at the NSF-CCLI/TUES Conference.
- Bransford, J., Vye, N., & Bateman, H. (2002). Creating high-quality learning environments: Guidelines from research on how people learn. In Graham, P. A., & Stacey, N. G. (Eds.), *The knowledge economy and postsecondary education: Report of a workshop. National Research Council. Committee on the Impact of the Changing Economy of the Education System. Center for Education*. Washington, DC: National Academies Press.
- Bransford, J. D., Brown, A., & Cocking, R. R. (Eds.). (2000). *How people learn: Brain, mind, experience, and school, Expanded edition*. Washington, DC: National Academies Press.
- Bruner, J. S. (1966). *Toward a theory of instruction*. Cambridge, MA: Belkapp Press.
- Buzan, T. (1991). *Use both sides of your brain: New mind-mapping techniques* (3rd ed.). New York, NY: Plume.
- Charney, A., & Libecap, G. D. (2003). *Impact of entrepreneurship education. Insights: A Kauffman Research Series* (p. 7). Kansas City, MO: Kauffman Center for Entrepreneurial Leadership.
- Coppola, B. P. (2011). Making your case: Ten questions for departments and individuals building an argument for work in discipline-centered education. *International Journal for the Scholarship of Teaching and Learning*, 5(1).
- Daly, S. (2008). *Assessment worksheet developed for Purdue University, School of Engineering Education PhD course, "Content, Assessment & Pedagogy: An Integrated Engineering Design Approach."*

- Duderstadt, J. J. (2008). *Engineering for a changing world: A roadmap to the future of engineering practice, research, and education*. The Millennium Project, The University of Michigan. Retrieved from <http://milproj.dc.umich.edu/>
- Dufresne, R. J., Gerace, W. J., Leonard, W. J., Mestre, J. P., & Wenk, L. (1996). Classtalk: A classroom communication system for active learning. *Journal of Computing in Higher Education*, 7, 3–47. doi:10.1007/BF02948592
- Fairweather, J. (2008). *Linking evidence and promising practices in science, technology, engineering, and mathematics (STEM) undergraduate education: A status report*. Commissioned Paper for the Board of Science Education Workshop, Evidence on Promising Practices in Undergraduate Science, Technology, Engineering, and Mathematics (STEM) Education. Retrieved from [http://www7.nationalacademies.org/bose/PP\\_Commissioned\\_Papers.html](http://www7.nationalacademies.org/bose/PP_Commissioned_Papers.html)
- Felder, R. M., & Brent, R. (2003). Designing and teaching courses to satisfy the ABET engineering criteria. *Journal of Engineering Education*, 92(1), 7–25.
- Fink, L. D. (2003). *Creating significant learning experiences: An integrated approach to designing college courses*. San Francisco, CA: Jossey-Bass.
- Goldman, S. L. (2004). Why we need a philosophy of engineering: A work in progress. *Interdisciplinary Science Reviews*, 29(1), 163–176. doi:10.1179/030801804225012572
- Gorman, G., Hanlon, D., & King, W. (1997). Some research perspectives on entrepreneurship education, enterprise education and education for small business management: A ten-year literature review. *International Small Business Journal*, 15(3), 56–78. doi:10.1177/0266242697153004
- Hutchings, P., & Shulman, L. S. (1999). The scholarship of teaching: New elaborations, new developments. *Change*, 31(5), 10–15. Retrieved from <http://www.carnegiefoundation.org/publications/sub.asp?key=452&subkey=613> doi:10.1080/00091389909604218
- Jamieson, L. H., & Lohmann, J. R. (2009). *Creating a culture for scholarly and systematic innovation in engineering education: Ensuring U.S. engineering has the right people with the right talent for a global society*. Washington, DC: ASEE.
- Johnson, D. W., & Johnson, R. T. (2004). *Assessing students in groups: Promoting group responsibility and individual accountability*. Thousand Oaks, CA: Corwin Press.
- Johnson, D. W., Johnson, R. T., & Smith, K. A. (1991a). *Cooperative learning: Increasing college faculty instructional productivity*. ASHE-ERIC Reports on Higher Education.
- Johnson, D. W., Johnson, R. T., & Smith, K. A. (1991b). *Active learning: Cooperation in the college classroom* (1st ed.). Edina, MN: Interaction Book Company.
- Johnson, D. W., Johnson, R. T., & Smith, K. A. (1998). Cooperative learning returns to college: What evidence is there that it works? *Change*, 30(4), 26–35. doi:10.1080/00091389809602629
- Johnson, D. W., Johnson, R. T., & Smith, K. A. (2007). The state of cooperative learning in post-secondary and professional settings. *Educational Psychology Review*, 19(1), 15–29. doi:10.1007/s10648-006-9038-8
- Koen, B. V. (2003). *Discussion of the method: Conducting the engineer's approach to problem solving*. New York, NY: Oxford University Press.
- Koen, B. V. (2009). The engineering method and its implications for scientific, philosophical, and universal methods. *The Monist*, 92(3), 357–386.

- Kuh, G., Kinzie, J., Schuh, J., & Witt, E. (2005). *Student success in college: Creating conditions that matter*. Washington, DC: Association for the Study of Higher Education.
- Kuh, G. D. (2008). *High-impact educational practices: What they are, who has access to them, and why they matter*. Washington, DC: Association for American Colleges and Universities.
- Light, R. J. (1992). *The Harvard assessment seminars: Second report*. Cambridge, MA: Harvard University.
- Mestre, J. P., Gerace, W. J., Dufresne, R. J., & Leonard, W. J. (1997). Promoting active learning in large classes using a classroom communication system. In E. F. Redish & J. S. Rigden, (Eds.) *The changing role of physics departments in modern universities: Proceedings of the International Conference on Undergraduate Physics Education—Part Two: Sample classes* (pp. 1019–36). Woodbury, NY: American Institute of Physics
- Milton, O., Pollio, H. R., & Eison, J. A. (1986). *Making sense of college grades*. San Francisco, CA: Jossey-Bass.
- Novak, J. D., & Gowin, D. B. (1984). *Learning how to learn*. New York, NY: Cambridge Press. doi:10.1017/CBO9781139173469
- Pace, D., & Middendorf, J. (Eds.). (2004). Decoding the disciplines: Helping students learn disciplinary ways of thinking. *New Directions for Teaching and Learning*, 98.
- Pascarella, E., & Terenzini, P. (2005). *How college affects students: A third decade of research*. San Francisco, CA: Jossey-Bass.
- Pascarella, E. T., & Terenzini, P. T. (1991). *How college affects students: Finding and insights from twenty years of research*. San Francisco, CA: Jossey-Bass.
- Pea, R. D., & Gomez, L. (1992). Distributed multimedia learning environments: Why and how? *Interactive Learning Environments*, 2(2), 73–109. doi:10.1080/1049482920020201
- Pellegrino, J. W. (2006). *Rethinking and redesigning curriculum, instruction and assessment: What contemporary research and theory suggests*. Paper commissioned by the National Center on Education and the Economy for the New Commission on the Skills of the American Workforce. Retrieved from <http://www.skillscommission.org/commissioned.htm>
- Pellegrino, J. W., Chudowsky, N., & Glaser, R. (2001). *Knowing what students know: The science and design of educational assessment*. Washington, DC: National Academies Press.
- Perkins, D. (1986). *Knowledge as design*. Hillsdale, NJ: Lawrence Erlbaum.
- Perkins, D. (2009). *Making learning whole: How seven principles of teaching can transform education*. San Francisco, CA: Jossey Bass.
- Roselli, R. J., & Brophy, S. P. (2002). Exploring an electronic polling system for the assessment of student progress in two biomedical engineering courses. *Proceedings of the American Society for Engineering Education Annual Conference*.
- Smith, K. A. (1996). Cooperative learning: Making “groupwork” work. In C. Bonwell & T. Sutherlund (Eds.), *Active learning: Lessons from practice and emerging issues*. *New Directions for Teaching and Learning*, 67, 71-82. San Francisco, CA: Jossey-Bass.
- Smith, K. A. (1998). Grading cooperative projects. In B. Anderson & B. W. Speck, (Eds.). *Changing the way we grade student performance: Classroom assessment and the new learning paradigm*. *New Directions for Teaching and Learning*, 78, 59-67. San Francisco, CA: Jossey-Bass.



- Smith, K. A. (2010). Social basis of learning: From small group learning to learning communities. *New Directions for Teaching and Learning*, 123, 11–22. San Francisco, CA: Jossey-Bass. doi:10.1002/tl.405
- Smith, K. A., Douglas, T. C., & Cox, M. (2009). Supportive teaching and learning strategies in STEM education. In R. Baldwin, (Ed.). *Improving the climate for undergraduate teaching in STEM fields. New Directions for Teaching and Learning*, 117, 19–32. San Francisco, CA: Jossey-Bass.
- Smith, K. A., Johnson, D. W., & Johnson, R. T. (1981a). The use of cooperative learning groups in engineering education. In L. P. Grayson & J. M. Biedenbach (Eds.), *Proceedings Eleventh Annual Frontiers in Education Conference*, (pp. 26–32). Rapid City, SD. Washington, DC: IEEE/ASEE.
- Smith, K. A., Johnson, D. W., & Johnson, R. T. (1981b). Structuring learning goals to meet the goals of engineering education. *English Education*, 72(3), 221–226. doi:10.1080/0304379810060210
- Smith, K. A., Sheppard, S. D., Johnson, D. W., & Johnson, R. T. (2005). Pedagogies of engagement: Classroom-based practices. *Journal of Engineering Education. Special Issue on the State of the Art and Practice of Engineering Education Research*, 94(1), 87–102.
- Streveler, R., Borrego, M., & Smith, K. A. (2007). Moving from the “scholarship of teaching and learning” to “educational research:” An example from engineering. *To Improve the Academy*, 25, 139–149.
- Sullivan, W. M. (2005). *Work and integrity: The crisis and promise of professionalism in America*. San Francisco, CA: Jossey Bass.
- Svinicki, M. D. (1999). New directions in learning and motivation. *New Directions for Teaching and Learning*, 80, 5–27. San Francisco, CA: Jossey Bass. doi:10.1002/tl.8001
- Wankat, P. C., Felder, R. M., Smith, K. A., & Oreovicz, F. (2002). The scholarship of teaching and learning in engineering. In Huber, M. T., & Morreale, S. (Eds.), *Disciplinary styles in the scholarship of teaching and learning: Exploring common ground*. Washington, DC: American Association for Higher Education and the Carnegie Foundation for the Advancement of Teaching.
- Wiggins, G., & McTighe, J. (1998). *Understanding by design*. Alexandria, VA: ASCD.
- Wiggins, G., & McTighe, J. (2005). *Understanding by design, expanded* (2nd ed.). Alexandria, VA: ASCD.
- Wulf, W. A. (1998, Winter). The image of engineering. *Issues in Science and Technology*. Retrieved July 7, 2011, from <http://www.issues.org/15.2/wulf.htm>