

## **Theoretical Foundations for the Foundation Coalition Core Competencies**

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### Abstract

The Foundation Coalition was funded in 1993 as the fifth coalition in the National Science Foundation's Engineering Education Coalitions Program, and is currently in the seventh year of a ten-year project. The member institutions have changed since its formation and now include Arizona State University, Rose-Hulman Institute of Technology, Texas A&M University, Texas A&M University - Kingsville, the University of Alabama, the University of Massachusetts - Dartmouth, and the University of Wisconsin. All campuses have developed improved engineering curricula and learning environment models and have incorporated those models into their institutional fabric. As part of its strategic plan, the partner campuses in the Foundation Coalition have focused their efforts on improving their competence in seven theories of pedagogy; these seven pedagogical theories are referred to as the core competencies of the Foundation Coalition. The seven core competencies are 1) curriculum integration, 2) cooperative and active learning, 3) teamwork and collaboration, 4) technology-enabled learning, 5) assessment-driven continuous improvement, 6) recruitment, retention, and graduation of women and underrepresented ethnic minorities, and 7) management of change. Once proposed as core competencies, the Foundation Coalition must answer at least one question. What are the theoretical foundations that suggest these seven core competencies will positively impact engineering education? The paper will review the literature to provide the theoretical foundations that indicate increasing abilities in these seven core competencies will positive impact engineering education.

### I. Introduction

In 1993 the National Science Foundation funded a coalition of seven schools, the Foundation Coalition<sup>16</sup>, with the vision of becoming a recognized leader in establishing a new culture of engineering education in the nation. During the first five years of funding the coalition concentrated on creating pilot programs, primarily focused on the first two

years of the undergraduate engineering degree. These pilot programs required different behaviors on the part of faculty, retained students at a higher rate (particularly women and underrepresented ethnic minorities) and generated superior learning outcomes. The current five years of funding are focused on 1) how to institutionalize these pilot curriculum programs, 2) how to systemically improve engineering education, and 3) how to build sustainable models of assessment and evaluation that support systemic improvement.

As part of its strategic plan, the partner campuses in the Foundation Coalition have focused their efforts on improving their competence in seven theories of pedagogy; these seven pedagogical theories are referred to as the core competencies of the Foundation Coalition. The seven core competencies are 1) curriculum integration, 2) cooperative and active learning, 3) teamwork and collaboration, 4) technology-enabled learning, 5) assessment-driven continuous improvement, 6) recruitment, retention, and graduation of women and underrepresented ethnic minorities, and 7) management of change. For each core competency, the Foundation Coalition must answer at least one question. What are the theoretical foundations that suggest these seven core competencies will positively impact engineering education?

## II. Core Competencies: Definition

Before answering the questions, let's define the core competencies. Each core competency refers to a pedagogical theory (or set of theories) in which Foundation Coalition partners will work to increase their competence. Curriculum integration refers to theories of pedagogy in which students and faculty work to make connections: between topics in a discipline, between topics in different disciplines, between subjects they are studying and their career aspirations. Cooperative and active learning refers to theories of pedagogy in which students in a classroom are doing more than simply listening to a lecture; instead, they are engaged (actively and cooperatively) in reading, writing, reflecting, discussing, critiquing, and self-assessing. This type of engagement and activity on the part of students implies an equally dramatic change in classroom pedagogy and management on the part of faculty. Foundation Coalition initiatives are focused on helping faculty make the changes that will in turn help students. Teamwork and collaboration refers to theories of pedagogy in which students and faculty do more than simply state that they need to develop their collaborative skills to participate in teams and communities. Instead, faculty design and explicitly prepare resources and design activities that help students to develop these skills. Technology-enabled learning refers to theories of pedagogy in which students do more than simply use technology on isolated exercises. Instead, faculty change physical classrooms and classroom pedagogy to help students routinely use technology inside and outside the classroom to improve learning: either to make learning more effective with the same resources, more efficient with the same quality of outcomes, or both. Assessment-driven continuous improvement refers to theories of pedagogy in which faculty develop assessment, evaluation, and feedback processes that promote continuous improvement of the educational experience. Recruitment, retention, and graduation of women and underrepresented ethnic minorities

refer to theories of pedagogy that are necessary precursors to improving the diversity of the engineering workforce in this country. Such diversity at the undergraduate level and beyond requires both that faculty and administrators have the motivation to increase diversity and that faculty and administrators take steps to make the learning environment more hospitable to diverse students. The Foundation Coalition aims to support faculty and administrators in both of these areas. Management of change does not refer to theories of pedagogy. Instead, it refers to theories of organizational development that focus on increasing the capacity of an institution to initiate and sustain curricular innovations. The paper will review the literature to provide the theoretical foundations that indicate increasing faculty with these seven core competencies will positively impact engineering education.

### III. Theories of Learning and Teaching

Each theory of learning and teaching has two parts. The first part is a theory of how a learner acquires, assimilates and retains information. Theories that address the learner's acquisition, assimilation and retention of information will be referred as theories of knowing. The second part is a theory of how a teacher can facilitate the processes described by the theory of knowing. Theories that address facilitation of learning will be referred to as theories of pedagogy. Together a theory of knowing and a theory of pedagogy form a theory of learning and teaching.

Why is a distinction between theories of knowing and theories of pedagogy necessary? The distinction may help readers organize the vast amount of material that is available on learning and teaching. Some of the material presents theories of knowing; some of the material presents theories of pedagogy; some of the material provides ideas that relate theories of knowing and theories of pedagogy; and finally some of the material presents combinations of all three types of ideas. In addition to helping to organize the material, distinguishing material on theories of knowing and material on theories of pedagogical may help readers use the literature to improve their decisions about what to do in the classroom. The following paragraph illustrates distinctions between theories of knowing and theories of pedagogy.

"A common misconception regarding "constructivist" theories of knowing (that existing knowledge is used to build new knowledge) is that teachers should never tell students anything directly but, instead, should always allow them to construct knowledge for themselves. This perspective confuses a theory of pedagogy (teaching) with a theory of knowing. Constructivists assume that knowledge is constructed from previous knowledge, irrespective of how one is taught -- even listening to a lecture involves active attempts to construct new knowledge. The story related in the book *Fish is Fish*<sup>25</sup> and attempts to teach children that the earth is round both demonstrate why simply providing lectures simply does not work.<sup>9</sup> Nevertheless, there are times, usually after people have first grappled with issues on their own, that "teaching by telling" can work extremely well."<sup>9</sup>

First, consider theories of knowing. Unfortunately, for beginners inquiring into theories of knowing, the field is not simple and easily categorized. For example, the Theory Into Practice (TIP) database<sup>22</sup> holds fifty different theories of knowing. These theories are not isolated. Instead, some overlap with others making it difficult to select a single theory of knowing upon which to build a theory of learning and teaching. This paper will not describe each of theories. Instead, it is hoped that readers will investigate, select, and explore some of the theories while maintaining distinctions between these theories of knowing and theories of pedagogy.

It is nearly impossible for the numerous faculty across the Foundation Coalition partners to subscribe to a single theory of knowing. In spite of the diversity, faculty who developed the original pilot curricula generally subscribe to a constructivist theory of knowing.<sup>10</sup> That is, they believed the students use their existing knowledge to construct cognitive networks in which to assimilate new information. Second, they generally subscribe to social constructivist theory that asserts that social interaction plays a fundamental role in the development of cognition.<sup>42</sup>

Once a teacher has adopted a theory of how students assimilate and retain information, then he/she selects a pedagogical approach to use in the class. Before selecting a pedagogical approach a teacher makes at least two decisions based on her/his domain-specific understanding. First, a teacher selects the body of material around which the students will be focused. For example, a teacher who is teaching the first introductory physics course establishes the set of topics that students will encounter. Second, a teacher selects levels of learning for the chosen topics. For example, if a teacher uses Bloom's Taxonomy<sup>39</sup> to define levels of learning, then his/her selection of pedagogical approaches depends on whether he/she targets the comprehension level or the synthesis level of learning for a particular topic. The two decisions impact the pedagogical approach, but they are not informed by theories of pedagogy.

Once topics and levels of learning are selected, then both general pedagogical knowledge and domain-specific pedagogical knowledge should inform choices of pedagogical approaches. General pedagogical knowledge provides generic advice for selecting a pedagogical approach. One example of the type of generic advice that could be offered is "Cooperative learning facilitates learning better than only lectures." However, general pedagogical knowledge is insufficient. In addition, pedagogical knowledge that is specific to a domain, e.g., mathematics or physics must also inform selection of pedagogical approaches. The second type of pedagogical knowledge is referred to as content pedagogical knowledge.<sup>9</sup> Content pedagogical knowledge identifies specific conceptual barriers that teachers encounter when teaching specific topics and offers approaches that help students to surmount these barriers. Content pedagogical knowledge is the "interplay of domain knowledge and pedagogical knowledge"<sup>9</sup> and its existence "contradicts a commonly held misconception about teaching -- that effective teaching consists of a set of general teaching strategies that apply to all content areas."<sup>9</sup> Therefore, teacher working to improve can learn more about general pedagogical and content pedagogical knowledge.

With a brief and very superficial review of the theories of learning and teaching as context, theoretical foundations for each of the core competencies of the Foundation Coalition will be examined.

#### IV. Curriculum Integration

DEFINITION: Within the Foundation Coalition curriculum integration is a theory of pedagogy that asserts that learning can be facilitated by structuring learning activities so as to help students build connections among the topics that are presented. In our model, students are learning a number of topics simultaneously. Since students must actively construct new cognitive networks based on existing knowledge in which to hold the new information, faculty reasoned that students could more easily and effectively assimilate new information if they coordinated topics across different subjects so that topics presented simultaneously in different courses were closely related. Further, faculty reasoned that they could facilitate assimilation if they worked to construct lectures and other learning activities that acknowledged other topics that students were learning and pointed out the links between these topics and the information that they were presenting. Support for this approach can be found in other sources.

"The context in which one learns is also important for promoting transfer. Knowledge that is taught in only a single context is less likely to support flexible transfer than knowledge that is taught in multiple contexts. With multiple contexts, students are more likely to abstract the relevant features of concepts and develop a more flexible representation of knowledge."<sup>9</sup>

As an example of how curriculum integration may be applied in an engineering curriculum, consider the following example constructed by physics and mathematics faculty at the University of Alabama. They viewed their system as containing both the mathematics and physics courses and reorganized material to reinforce connections such as the ones described below.

"Early in the first semester, the mathematics faculty introduced the symbolic algebra program Maple as an aid in plotting and understanding of functions - trigonometric, exponential, logarithmic, normal distribution, etc. This allowed the rapid introduction of the concept of the derivative and slope of curves in the mathematics course. The physics course created an immediate application for this material by introducing the one-dimensional kinematics of particles and rigid bodies, i.e., velocity and acceleration."<sup>30</sup>

In addition to connections between topics that engineering students are currently studying, there is another set of connections that appears to be missing to students and for which many engineering curricula provide little support. Students want to glimpse connections between what they are currently studying and their perceptions of their careers after graduation. Nomenclature provides one set of walls between topics currently being studied and perceptions of careers. These are engineering students and they are studying courses named calculus, physics, chemistry, and English. Course names don't help students to see or understand connections. The nature of activities provides another set of walls. Many engineering students see engineering practice after graduation as activities of creation, e.g., designing and building a new computer, designing and building a refinery, or designing and building a bridge. However, their current learning activities are often analytical or computational in nature. Often students

do not see connections between synthetic activities in their perceived future and analytical activities required in their present courses.

To help students make these connections Foundation Coalition partners have created sets of freshman design projects that are based on “real world” problems and that integrate the areas of engineering, mathematics, and the sciences. Several of these can be found on the web site (<http://foundation.ua.edu>), and focus on areas such as: power distribution layout, stream pollution remediation, and analog computer design. In addition, Texas A&M University has uses actual industry case studies across its entire freshman class. Industry representative present the case studies, assign the task to be accomplished and listen as student teams present their reports. Although the nature of the freshman projects varies across Foundation Coalitions, student comments indicate the projects have helped students make connections between their science, engineering and mathematics topics and their future careers.

## V. Cooperative and Active Learning

In a sense, active learning, cooperative learning and collaborative learning are misnomers because each has less to do with theories of knowing and more to do a theory of pedagogy. However, the terminology is so well entrenched that this paper will not try to change widely used vocabulary.

### Active Learning

The literature shows that students must do more than listen in order to truly learn.<sup>11</sup> However, one of the more extensive surveys of U.S. professors found that lecturing is the mode of instruction in 89% for physical scientists and mathematicians<sup>40</sup>. Although there is no one accepted definition of active learning and the term means different things to different people,<sup>5, 13, 34</sup> coalition faculty offer the following as characteristics of active learning<sup>8</sup>:

- Students are engaged in more activities than listening (reading, discussing, writing, problem solving).
- Students are involved in higher-order thinking (analysis, synthesis, evaluation).

There are several ways one can incorporate active learning in the classroom, all of which have been shown to be more effective than lecturing in terms of long-term retention of information, motivation toward further learning, applying information in new settings, or developing students' thinking skills.<sup>28,31,40</sup> These include modification of existing lectures, in-class discussion, and case studies or guided design.

### Cooperative Learning

One of the primary thrusts upon which the Foundation Coalition’s learning environment and curriculum models are based is cooperative learning. Cooperative learning is much more well defined than active learning; the Foundation Coalition faculty subscribes to the definition of cooperative learning as put forth by Johnson, Johnson, and Smith<sup>20</sup>, from which the following is taken.

Cooperative learning is the instructional use of small groups so that students work together to maximize their own and each other's learning. Considerable research demonstrates that cooperative learning produces higher achievement, more positive relationships among students, and healthier psychological adjustment than do competitive or individualistic experiences. These effects, however, do not automatically appear when students are placed in groups. For cooperative learning to occur, the learning groups must be carefully structured, which can be done in many different ways. For example, three broad categories of cooperative learning strategies are formal cooperative learning groups, informal cooperative learning groups, and cooperative base groups.

To be cooperative, a group must have clear positive interdependence, members must promote each other's learning and success face to face, hold each other personally and individually accountable to do his or her fair share of the work, use appropriately the interpersonal and small-group skills needed for cooperative efforts to be successful, and process as a group how effectively members are working together. These five essential components must be present for small-group learning to be truly cooperative.

## VI. Teamwork and Collaboration

**DEFINITION:** Working together in a way that builds on the unique talents of each team member and produces outcomes that surpass those possible by individuals alone.

Industry has recognized that today's engineering problems cannot be solved by individuals working alone, and that organized efforts by teams can address these complex problems more productively. Intel, Motorola, Xerox, Ford, General Motors, and AT & T have all publicly stated their commitment to a team-based work environment, and in the words of John Welch, CEO of General Electric, "If you can't operate as a team player, no matter how valuable you've been, you really don't belong at GE."

Recognizing the importance of teams to industry, engineering education has begun to stress this desired student outcome.<sup>2,3,4,15,29</sup> The engineering accreditation criteria, EC2000, now state that engineering programs must demonstrate that their graduates have, among other attributes, "an ability to function on multi-disciplinary teams."<sup>1</sup>

While it is important to develop the team skills of engineering students so that they can make the transition from academe to the workplace smoothly, developing these skills while still in college also increases students' potential for improved academic performance. This is the case in certain traditional team-based courses such as the capstone design course, and with today's interest in active learning theories of pedagogy, it is also true on a much wider scale.<sup>36</sup>

In addition, teamwork and collaboration are necessary to develop interpersonal and group processing skills required to support the active/cooperative learning framework. "Students do not come to school with the social skills they need to collaborate effectively

with others. So teachers need to teach the appropriate communication, leadership, trust, decision making, and conflict management skills to students and provide the motivation to use these skills in order for groups to function effectively."<sup>19</sup> Therefore, faculty have incorporated activities in Foundation Coalition curriculum to work on skills in several of the following areas: group processing, listening, effective meetings, small group interaction, team decision making, and team development.<sup>35</sup>

## VII. Technology-Enabled Learning

DEFINITION: Technology opens two different avenues for learning. First, new technology expands the range of what could be learned. For example, when a new programming language is introduced, its introduction is a new opportunity for learning. When a new spreadsheet is introduced, engineering majors could learn to use it for engineering calculations. The second avenue is that faculty and students could use technology to improve learning of existing topics. Part of the challenge in demonstrating that the use of technology can improve learning is the variety of ways in which technology has been used in attempts to improve learning. Faculty have used multimedia presentations; other faculty have used e-mail and web pages; still other faculty have used powerful computational tools such as Maple, Matlab, Microsoft Excel, and a host of others. Another part of the challenge is carefully defining the learning objectives to allow assessment of whether learning was improved. Foundation Coalition faculty have explored both avenues opened by technology.

Therefore, theoretical foundations for the use of technology to enhance learning are difficult to define because of the many different ways in which technology has been used in the classroom.

Mathematics faculty have debated for over a decade about whether the use of technology has improved instruction in calculus. Technological tools include graphing calculators, computers with spreadsheets, and computers running computer algebra packages. However, demonstrations of improved learning depend heavily on the chosen learning objectives. Often, faculty teaching calculus courses to students with access to powerful computer algebra packages are aiming at very different learning objectives than when they were teaching calculus courses without technology. Comparing student performances in the two different classes is like comparing apples and oranges because the two classes are targeted at different learning objectives. Questions about whether improvements in learning have occurred cannot be answered using assessment data alone. Instead, faculty must make value judgments regarding the different learning objectives.

## VIII. Assessment-Driven Continuous Improvement

DEFINITION: We will define assessment as the collection and analysis of data and evaluation as the assignment of meaning or interpretation of data as it relates to the quality of the activity.<sup>33</sup> The Foundation Coalition believes that student learning will be



improved by basing decisions about curriculum improvement on data collected through assessment plans that have been jointly developed by assessment professionals and faculty.

Assessment and evaluation (A/E) have been a major part of all Foundation Coalition activities since our formation. We have found, as have others,<sup>6</sup> that

- A/E works best when the program or activity they seek to improve has clear, explicitly stated goals.
- A/E is most effective when it is ongoing, not episodic.
- A/E is more likely to lead to improvement when it is part of a larger set of conditions that promote change.

The last point is of special import in this discussion of the seven core competencies. The competencies we have defined are most effective when practiced as a group. For example, assessment data alone may not convince faculty and administration to make curriculum changes. Assessment data must be part of a larger strategy that also incorporates expertise in change management. The Foundation Coalition vision of change is built on all seven core competencies.

## IX. Recruitment, Retention, and Graduation of Women and Underrepresented Ethnic Minorities

**DEFINITION:** Recruitment, retention, and graduation of women and underrepresented ethnic minorities is the ability to increase the diversity of the engineering education learning environment by attracting a larger percentage of women and underrepresented ethnic minorities into the study of engineering and retaining them through graduation.

A diverse student body can be defined as one that shows variety in its gender and racial or ethnic composition and resembles the population as a whole. One result of having a more representative student body is a better sense of community and hence a better learning environment for students.<sup>5</sup>

Experience in a diverse student community makes available to students a wider variety of experiences as they interact with students whose gender and culture differ from their own. Seeing different ways to identify, define, assess, and solve problems provides a useful learning environment for students as they progress through the engineering curriculum. If a larger number and greater variety of perspectives are brought to bear in discovering, defining, and solving problems, solutions are more creative.<sup>24,43</sup>

Successfully addressing team maintenance and process problems in groups with diverse members helps students gain useful abilities on conflict resolution, abilities increasingly sought by industry.<sup>26</sup> Today's graduates will be working in a fiercely competitive world market that is multicultural and globally-oriented.<sup>12,17,44</sup> Providing experiences in gender, cultural, or ethnic diversity will directly benefit our students, who are and will continue to be living in a diverse environment.

There are close relationships between this core competency and others. For example, it has been shown that pre-college girls have a preference for cooperative learning strategies<sup>14,18,21,23,32,38</sup>, and the role of pedagogy in retention, especially as it relates to women and minorities, has been documented.<sup>37,41</sup>

## X. Management of Change

**DEFINITION:** Increasing the capacity of an organization to initiate and sustain curriculum improvement efforts

Curriculum improvement efforts are sometimes viewed as a sequential process: 1) conceive an innovative curriculum idea; 2) develop a pilot test of the innovation; 3) refine the pilot until satisfactory; and 4) roll out revised curriculum for all students. The simple sequential perspective directs focus away from the primary target of change: people, namely faculty and students. Although everyone may agree in principle with the need to change the way faculty members act and teach, the emphasis will almost unconsciously tend to shift back to tinkering with the course, the technology, or the curriculum. Instead the essence of any major curriculum change is changing behavior, first faculty, and then students. If you want to change how engineers are educated, then you have to motivate the people responsible for the education environment to change their own behavior.

Once you shift the focus of your efforts to changing behavior, you are better prepared to respond to the most common element in change processes: resistance. Although resistance to change often carries a negative connotation, especially toward people who question or oppose a change, resistance is a natural, omnipresent phenomenon. Therefore, people who initiate curriculum change should not be surprised by its appearance or become defensive when questions are raised about the motivation or efficacy of the proposed change.

Resistance occurs because every individual changes through a sequence of stages. Many different sequences have been proposed, but the crucial concept is that each individual must work through a sequence of stages in order to change. Furthermore, individuals move through the sequences in response to different stimuli and at different rates. For example, how many times and in how many ways does a relatively simple change need to be announced before everyone "gets it". People know that once or twice is not enough. Now imagine the effort that is required even to communicate a major change successfully. In any organization, resistance to change arises because each individual is moving through the stages of change at different rates and at any time individuals are at several different stages in the change process.<sup>27</sup>

Resistance may also occur because the proposed change is not perceived to align with the culture of an institution. For example, faculty who learn about a Foundation Coalition curriculum initiative may perceive that, if the initiative is adopted for the entire college, then more time will be required to prepare for classes. Less time may be available for research activities. This type of change will not be aligned with the culture of an institution that places premium on only research activities. Curriculum advocates must anticipate the resistance and prepare responses that can help reduce resistance.

## XI. Conclusions

The paper has described the seven core competencies of the Foundation Coalition and attempted to provide a theoretical foundation for each. Emphasis on each individual competency is not the distinguishing feature of the Coalition. Instead, Coalition partners believe that improvements in learning and teaching are maximized by joint development of all seven core competencies.

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