AC 2007-758: DESIGN TEAM SKILLS CURRICULUM FOR INTERMEDIATE LEVEL PROJECT CLASS

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Design Team Skills Curriculum
For Intermediate Level Project Class

Abstract

Many engineering programs include a pre-capstone design class to prepare students for their senior design project. These classes typically teach the design process and teamwork skills in the context of shorter projects. To learn this type of engineering collaboration students need team practice time of discrete skills in a semi-controlled environment. Further, faculty monitoring and well-planned intervention into teams as they practice can greatly increase learning. However, scheduling team practice time into the regular class period seriously reduces the time to introduce the content and method of these skills. Instructors are often torn between providing adequate instruction and adequate practice time. As a result, successful learning of these skills is hampered. This paper describes an assessment-driven curricular development at Gonzaga University to teach collaborative engineering skills. The modular curriculum consists of three components:

1. An intelligent tutoring system prepares students with content knowledge before class practice. Formative and summative assessments are part of this system.

2. Structured team practice sessions centered on challenging case studies. Recorded and transcribed team interactions will be used to improve and verify that the case studies initiate higher-level group application of the skills.

3. A "coaching tool kit" equips the instructor with topic-specific intervention strategies to help teams master the skills. Recorded and transcribed student interactions before, during, and after interventions will be used to improve and validate the intervention strategies.

This project is in the early stage of a multi-year endeavor that is soliciting collaborators. Collaborators can join the project by using and assessing modules, creating new modules, or both. Our ultimate goal is to create an open community of practice that creates, improves, and uses this curriculum. Once mature, the curriculum will include a full array of modules that teach the skills that support engineering collaboration.

1. Background

The primary goal of engineering is to create new designs and improve existing ones.[1] Creating designs is typically done in a team environment. Engineers employ three broad categories of skills to execute this team-based work. These skills include *open-ended problem solving* applied to a variety of hurdles, *project management* to plan and manage workflow, and *teamwork skills* to optimize collaboration. These three broad areas of skills, labeled *design team skills,* regulate the more individual activities such as sketching, mathematical analyses, or CAD design.

Most universities introduce these skills in project-based design classes. Furthermore, at many universities design classes form a multi-year sequence. These classes strive to create authentic engineering design experiences. The students are assigned to small teams that create designs to solve real-world problems. During courses of this type, student teams are led through common phases of product development such as creating design specifications, generating conceptual designs, detailing designs, and prototyping. The primary pedagogy can be described as "learning by doing."

Many excellent textbooks are available that provide a rich description of the engineering design process. [2, 3, 4, 5, 6] These texts describe design as a set of sequential steps, which are then explained in detail. Discussion of project planning and some teamwork topics are also commonly included. It should be noted, however, that these texts focus on the global "design process" rather than focusing primarily on the execution of design team skills.

Since design is taught in authentic contexts and excellent references are available, one would expect the learning of design to be the centerpiece of engineering education. However, this is frequently not the case. Student teams often struggle with balancing competing demands of open-ended problems, managing workloads, planning tasks, and negotiating team interactions. The skills to navigate a design environment are new to most students. The design environment is certainly rich in learning opportunities, but it is also very complex.

Faculty also have their share of difficulty in teaching design. In a recent review of the pedagogy of design Dym, et al.[7] present an equivalent of the "State of the Union Address." They state:

> …the role of design in engineering education remains largely as stated by Evans et al. in 1990: "The subject [of design] seems to occupy the top drawer of a Pandora's box of controversial curriculum matters, a box often opened only as accreditation time approaches. Even 'design' faculty—those often segregated from 'analysis' faculty by the courses they teach—have trouble articulating this ***elusive creature*** called design."[8] (emphasis by author)

We believe that some of the "elusive creatures" of a design curriculum are simply design team skills. On the surface, these skills may appear easy to master because they are not difficult to comprehend. However, it is difficult to develop proficiency in these skills because they require developing correct interactional habits. This is somewhat analogous to learning to play a piano. Though it is easy to explain how a note on a page corresponds to striking a key, it is far more difficult to actually learn to play music.

Teaching these skills represents a significant logistical and resource hurdle for faculty. Since the skills are interactional, the students must practice them with each other to become proficient. However, mere practice is not sufficient, but rather correct practice. Hence, instructor guidance during practice helps considerably. The available time for such practice is during class, since the faculty and the students are all present. However, adding practice time in class displaces other necessary activities, such as lecture or team project time.

One solution to this logistical hurdle is to create on-line lectures so that class time is freed for guided student practice of design team skills. This curriculum development intends to create, assess, and improve such curricular materials. The curriculum is intended for intermediate level design classes, though it may be used in lower or higher level classes. The community developing the curriculum is actively soliciting more members.

2. Team Design Skills Curriculum

2.1. Curriculum Overview

The design team skills (DTS) curriculum is modular with each module centering on student practice of a targeted skill. Each module has three parts:

1. *Practice Cases with Embedded Complexities* that structure student tasks and roles in practice sessions.
2. *On-line Lectures with Embedded Assessments* that present the content and application to students before practice sessions.
3. *Coaching Tool Kit* that prepares the instructor to identify student misapplications of each skill and provides strategies to effectively redirect teams during practice sessions.

The curriculum primarily focuses on small team practice. The preparatory on-line lectures and instructor coaching support this practice. The initial curriculum targets 10 “stand-alone” modules. Suites of modules combine to teach larger holistic skills. Figure 1 diagrams the structure of the modules and Table 1 describes the initial 10 modules.

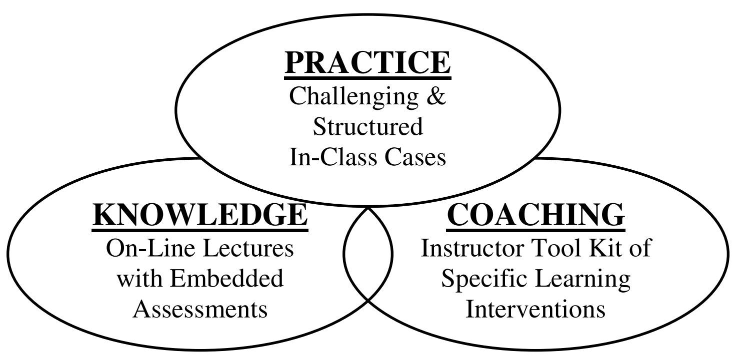

Figure 1: The Three Elements of Each Module in the Curriculum

Skill Area	Module Description
Team Interactions	*Active listening:* Students learn to rephrase and summarize teammates' statements to test for agreement. This skill is useful in building consensus and working collaboratively.
	Giving and receiving feedback: Students learn how to structure and give constructive feedback to their teammates. Such feedback is essential to improving the performance of individual members and the team.
	Task conflict vs. Personal conflict: Students learn how to keep and/or move disagreements into the task domain and out of the personal domain. Maintaining a team culture where ideas can be challenged while people are affirmed is necessary for excellent team performance.
Problem Solving	*General problem solving process:* Students learn how to apply an open-ended problem solving process to a wide variety of problems. Following a process increase the quality of solutions and decreases the time to a solution.
	Problem identification & goal definition: Students learn methods to identify and define the goal state for open-ended problems. This includes creating product design specifications for open-ended problems that are specifically design related.
	Concept generation: Students learn methods to generate alternative design concepts. Creation of alternatives and overcoming "locking on" to a single alternative is a basic component of open-ended problem solving in design.
	Creating and applying assessment criteria: Students learn to distinguish between personal opinion and objectively stated criteria for assessing the quality of a proposed solution to an open-ended problem. Correctly using assessment criteria is a basic skill in open-ended problem solving.
Project Management	*Action items & individual planning:* Students learn to decompose their tasks into basic steps and organize those steps to decrease time to completion and increase collaboration.
	Project plans & schedules: Students learn to decompose a small project into parts (work breakdown) and organize them into a workable schedule. Students also learn the protocols of maintaining and updating a schedule.
	Meeting protocols and individuals' roles: Students will learn to structure agendas to meet team meeting needs. Students will also learn the responsibilities and protocols each member has to keep a meeting on task.

Table 1: Initially Proposed Modules.

2.2. Structured Practice Sessions

Each practice session centers on a very challenging case. These cases embed typical complexities and/or interdependencies that are commonly found in professional settings. Student teams apply a targeted skill to resolve the embedded complexities while creating professional artifacts appropriate for each case such as product specifications, assessment criteria, or meeting agendas. In each of these sessions, defined student tasks and roles are used to guide students toward expert practice of each skill. Additionally, the sessions guide students to self-monitor their use of the skills. These sessions are scoped to fit within a 50-minute class schedule.

2.3. On-line Lectures of Knowledge and Methods

On-line lectures present factual knowledge, conceptual framework, common methods, and self-monitoring strategies for each skill. Short conceptual assessment quizzes are embedded throughout the lecture content. These quizzes target common misconceptions at both a conceptual and practical level. Incorrect student responses to questions redirect the lecture to supplemental explanations that address misunderstandings. This basic level of embedded formative assessment is expected to clarify factual understanding before practice sessions begin.

Lectures are administered through common educational software (such as Blackboard Learning Systems®) so that nominal class credit for attending on-line lectures motivates students to complete them before classroom practice sessions. On-line summative quizzes are administered following each lecture. Detailed synopses of each skill are also distributed on-line for student notes.

2.4. Instructor Coaching of Teams

During each session, the instructor acts as a coach, directly observing and redirecting team practice as needed. Since student mastery of challenging cases involves *correct* practice and not merely practice, the instructor provides a much-needed learning resource. The combination of practice on challenging cases and available learning assistance greatly increases the achievable learning outcomes. To equip instructors for this role, a "coaching tool kit" is being developed. This tool kit enables the instructor to identify common student misconceptions, procedural difficulties, and dialogue patterns signifying depth of group processing. Coupled with these identification tools are intervention strategies to redirect team discussions.

3. Supporting Literature

Two broad areas of knowledge are being combined to create the curriculum. First, domain knowledge is drawn from the wealth of literature in teamwork, project management, and problem solving. Second, curricular materials and instructional methods are based on literature on active learning and instructor intervention strategies.

3.1. Domain Knowledge

The available literature on problem solving, project management skills, and teamwork skills is very substantial. A quick Internet subject search yielded hundreds of titles (in some cases thousands) on teamwork, leadership, management, and problem solving. These books encompass a range spanning common sense practical self-help books to empirically based treatises.

There are also several textbooks specifically written for design classes.[2, 3, 4, 5] Some topics on teamwork and project planning are typically woven into these texts as well. Textbooks are also available on topics in teamwork and project planning.[9, 10] These texts present several topics in teamwork in practical step-by-step methodologies. In a broader view, LaFasto and Larson[11] provide a rich description, based on substantial empirical evidence, of attributes of strong teammates and leaders. Countless texts written for managers are also available.

The online lectures and accompanying synopses for each module will draw on appropriate sources to present a solid theory and practice of each skill. These resources are intended to present the practice of skills to complement content in the common design texts. In this way the modules can be interwoven into a course using one of these texts. However, each module will be complete in itself so that it can be used independent of any textbook.

3.2. Instructional Methods

Instructional methods that actively engage students have dramatically increased in engineering education the past twenty years.[12, 13, 14] These methods fall under the umbrella term of *active learning* and include collaborative, cooperative, and problem-based learning.[13] Data supporting the efficacy of these methods is found in many areas in the educational literature.[13, 14] Summary of current best practice and suggestions for implementing these methods are also reported.[15, 16, 17] However, many significant areas of active learning are yet to be investigated[14] and hence a prescription for the "best" method for this curriculum is not known.

The initial practice sessions will combine elements from "Team-Based Learning" (Michaelsen[18]) and the "Structural Approach" to active learning (Kagan & Kagan[19]). Michaelsen prescribes five elements to create effective group assignments:

1. Individual accountability,
2. Close student proximity,
3. Tasks that innately require interaction,
4. External comparison and/or feedback and,
5. Rewards for group performance (portion of grade).

Michaelsen further describes how to incorporate each of these elements into team assignments, which are equivalent to DTS practice sessions. His approach relies on high task focus, created by effective team assignments, to promote teamwork. The team assignments do not prescribe interaction processes to aid in completing the group assignments.

In contrast to Team Based Learning, the structural approach to active learning prescribes interaction sequences (e.g. "think-pair-share") to promote learning. Kagan and Kagan have catalogued many such structures. Each specific structure produces certain interaction patterns, which makes it suited for certain specific learning outcomes. The catalogue of these structures covers many learning outcomes appropriate for the practice sessions. These interaction structures are then filled with content to create a lesson.

To apply the structural approach to the practice sessions, interaction structures will be chosen that mimic common professional engineering forms of interaction (e.g. roundtable discussions). Since the chosen structures will represent common industry practices, the students will implicitly learn professional communication.

The instructor's role of coach is very similar to the role of learning facilitator as described in the Pacific Crest Faculty Guidebook.[20] This Guidebook (and its parent organization Pacific Crest) provides many principles for educational coaching as well as practical methods to embody these principles. These published methods were created and tested by a consortium of faculty at multiple institutions in several disciplines. The initial version of the coaching tool kit will draw heavily from this resource.

4. Assessment Criteria for Curriculum Effectiveness

Each element of each module will be assessed in use and subsequently improved. The criteria for effectiveness are drawn primarily from cognitive sciences. The field of cognitive science models the human mind as an information processor.[21] Many studies in this field have demonstrated that learning is a natural phenomenon that follows common patterns. Donovan and Bransford[22] summarize these learning patterns as three principles of learning. These principles describe learning conditions and set the performance goal for the curriculum.

4.1. <u>Principle #1: Engaging Prior Understandings</u>

Learners bring deep-rooted preexisting understandings, based on life experience, to the classroom. This individualized preexisting knowledge is the platform on which new learning takes place. Learners literally re-create the knowledge being learned upon their preexisting knowledge. As such, learning is strongly preconception driven. Inadequate or incorrect preconceptions can cause learners to reject or misinterpret new learning. If faulty preconceptions are not addressed, students often revert to their former experience-based preconceptions and actions after leaving the classroom. This is especially true in social learning that engages cultural norms (such as in team interactions).

4.2. <u>Principle #2: Mutually Supportive Factual Knowledge and Conceptual Frameworks</u>

Learning with understanding involves both acquiring factual knowledge and organizing it into supporting conceptual frameworks (schema). Factual knowledge learned without schema is shallow. Conversely, schemas become clearly understood when illustrated by multiple specific examples. Studies have shown that experts remember and access more information than novices because they organize the information in schema. In contrast, novices are unlikely to discern relevant schema or concepts. "People usually need some help to grasp such organizing concepts."[23] Consequently, instruction should be organized by relevant schema and such schema explicitly presented to the students. Furthermore, when factual knowledge is learned within an organizing schema, the proper application of such learned knowledge is more certain.

4.3. Principle #3: Importance of Metacognition

People have the ability to think about their thinking, even while thinking. This thinking about one's thinking is called metacognition. When applied to learning, metacognition takes the form of self-monitoring of the learning process. This self-monitoring is fundamental to mastery of a subject. Self-monitoring involves consciously defining learning goals and monitoring one's progress of understanding. Self-monitoring also includes an awareness of the need to check how new information fits with previously learned information.

Metacognition also plays an important role in the practice of skills. Experts typically self-monitor their tasks as they perform them. This metacognitive knowledge is context and task specific. Consequently, explicitly teaching task specific metacognition is an important complement to teaching factual knowledge in relevant schema. Furthermore, explicit practice of task specific metacognition is important to mastery of a skill.

5. Creating, Assessing, and Improving Modules

Figure 2 shows the process for developing modules. The steps of creating and improving the modules are inside the dashed box while inputs to and outputs from the process are shown outside the dashed box. The module development process is iterative, where modules are initially developed, assessed in use in a class, and improved. The initial design and subsequent assessment and improvement of modules are guided by the principles of learning. With each successive improvement cycle, the process yields improved modules and best practices for designing modules, as well as other research data.

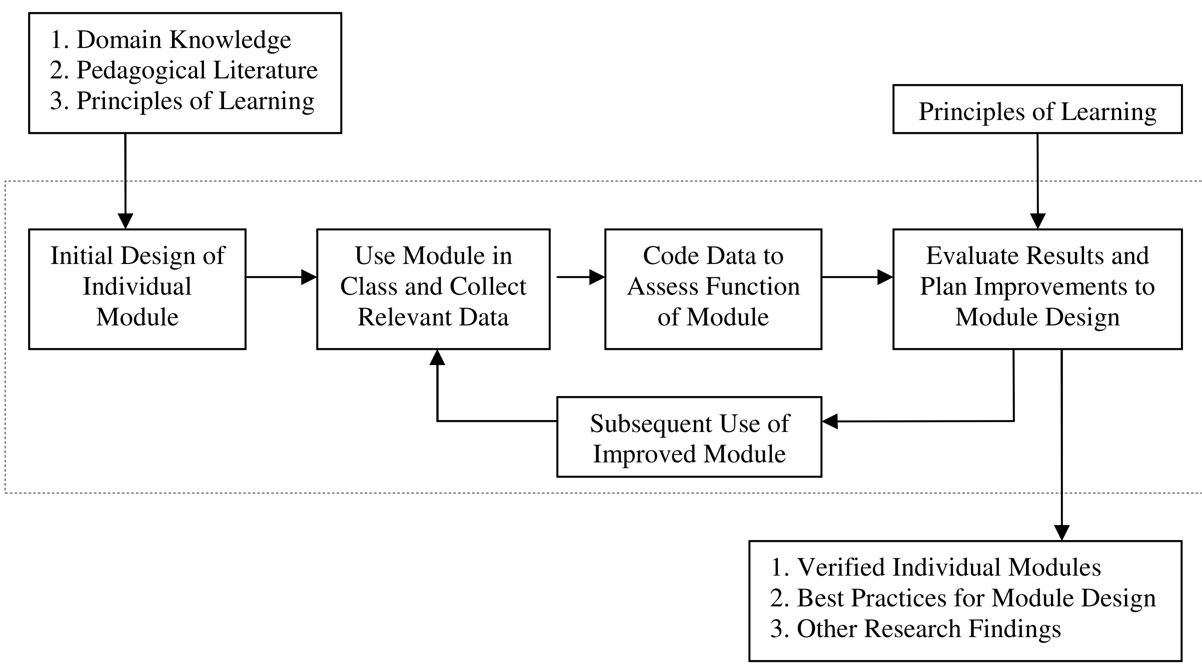

Figure 2: Module Creation, Assessment, and Improvement Process

5.1. Step 1: Initial Design of Modules

Creating each module begins with identifying domain knowledge and appropriate expert practices. Once the knowledge and practices are clearly identified, the three components of each module will be created. The on-line lectures with embedded assessments will be created to transfer the "what," "why," and "how" of each skill. These will use a traditional lecture format. The practice sessions will be created around challenging cases and be formatted as classroom handouts. Some cases may include video or other media presented by the instructor. The coaching tool kit will be created to contain the general skills of facilitating learning and module specific tools. The initial module specific tools will be based on *anticipated* student misconceptions and procedural difficulties with each skill.

5.2. Step 2: Module Use and Data Collection

Module effectiveness data will be collected in use in regularly scheduled classes. The data includes:

1. On-line quizzes immediately following lectures
2. Video/Audio recording of small team interactions during practice sessions
3. Instructor reflective notes of apparent effectiveness of coaching during practice
4. Summative assessment of student learning following multiple modules

5.3. Step 3: Data Coding and Module Assessment

5.3.1. *Recorded Small Team Interactions*

During each practice session, a video/audio recording will be made of one of the student teams. Each recording will be transcribed and subsequently coded to identify the depth of group cognitive processing, group mastery of the skill, and aspects of individual participation and interaction. Standard techniques and protocols for coding qualitative data will be followed.[24, 25, 26] The three principles of learning will form the primary theoretical lens to sort "good" from "poor" group processing. Interactions that show evidence that the three principles of learning are being met will be considered good. Group processing that lacks such evidence will be deemed poor. In a preliminary study at Gonzaga University,[27] we have found this method invaluable in understanding how students process specific team directions and cases.

Transcribed dialogues will also be coded to identify opportunities for coaching. Further, student processing following coaching interventions will be scrutinized for the effectiveness of the redirection.

5.3.2. On-line Quizzes Following On-line Lectures

Quizzes administered immediately following on-line lectures will test content delivered in the lectures. Aggregate correct response rates, question-by-question, will identify concepts within lectures that need further reinforcing. The rates may also identify problematic concepts to target in the coaching tool kit.

5.3.3. Instructor Reflective Notes of Coaching

Instructors will record reflective observations of their coaching following each structured practice session. These observations will be used to guide the development of the tool kit.

5.3.4. Summative Assessment of Student Learning

Summative learning assessments will be collected using analytic rubrics adapted from the TIDEE project.[28] These assessments will check the holistic effectiveness of curriculum.

5.4. Step 4: Module Improvement

5.4.1. Improvements to the Practice Sessions

The transcriptions of team conversations during practice provide a direct window into group processing of both the instructions and the case. In our previous use of this method[16] we found that emergent trends within single sessions and across multiple sessions frequently "suggested" improvements to the session design. Subsequent sessions, designed with the suggested improvements initiated better team processing. We anticipate that with successive iterations the practice sessions will initiate the desired learning environment with high frequency. We also anticipate that "best practices" for active session design will emerge.

5.4.2. Improvements to the On-line Lectures

The aggregate quiz results will quickly identify areas for improvement in the lectures. We expect these improvements will be fairly straightforward.

5.4.3. Improvements to the Coaching Tool Kit

The coaching tool kit will be improved based on three different assessments. First, opportunities for coaching intervention will become evident in the transcriptions. We anticipate that general rules to identify these opportunities will emerge across several transcripts. Second, the effectiveness of actual interventions will be recorded and scrutinized. Finally, the coaches' self-reflective notes, though not a direct assessment of coaching effectiveness, will provide valuable insight into improvement plans.

6. Project Research Goals

Though this project is primarily a curriculum development, it will also yield educational research results in two areas. First, the iterative collection and coding of assessment data will create an empirically based "best practices" for designing active learning sessions. These verified best practices may be transferable to the design of other active learning contexts. Second, the Coaching Tool Kit will also be empirically based. Since active learning methods are increasingly common in engineering education, informing the complementary faculty role during active learning is valuable. Our aim is to publish results within ASEE venues as the project progresses.

7. Solicitation for Collaborators, Community of Practice

We are soliciting design faculty to join a community that creates, uses, and improves modules within the curriculum. Community members will be welcome to engage at their preferred level of involvement, from those simply using or trying the curriculum to those actively creating new modules. The community will incubate educational research methods within its members. Our aim is to apply a research paradigm to all curricular development and publish peer-reviewed articles in appropriate venues. If you are interested in joining the community, please contact the authors via email at zemke@gonzaga.edu.

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