Session 3425

Framework for Developing and Implementing Engineering Design Curricula

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Abstract

For the last eight years, the Transferable Integrated Design Engineering Education (TIDEE) consortium has provided leadership in design education by formulating outcome statements, creating instructional materials, and delivering faculty development workshops to help engineering educators respond to ABET expectations in the areas of design, teamwork, and communication. This paper examines the framework used by TIDEE curriculum developers to create and implement over 100 learning activities that appeal to diverse student populations. Key elements of the TIDEE framework include: (1) structured collaborative activities that engage students, (2) explicit attention to procedural and metacognitive knowledge that students can apply in new design team contexts, and (3) integration of formative and summative assessments to elevate learning and to document achievement of key learning outcomes. This paper summarizes the educational philosophy used to create and sequence design-based learning activities that can be downloaded from www.tidee.cea.wsu.edu.

Changing Focus of Design Education

Engineering education has remained essentially unchanged for decades, with a focus on the teacher and what is taught, in contrast to the student and what is learned. Historically, this approach operates in an open-loop system where teachers pour forth the same content regardless of student needs. The emergence of student-centered classrooms and outcomes assessment in the last decade has profoundly changed the paradigm for teaching and learning across higher education[1].

Engineering Criteria 2000 (EC 2000) adopted by the Accreditation Board for Engineering and Technology (ABET), which instituted requirements for outcomes definition and assessment, created serious confusion among engineering educators[2,3]. This resulted from the limited faculty training in educational concepts such as learning objectives, outcomes, and assessment. As a result, many faculty members displayed limited interest in transforming their educational practices. Other faculty members saw EC 2000 as a catalyst for continuous improvement, but lacked the expertise to modify their course

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design and teaching techniques to an outcomes-based environment.
The Transferable Integrated Design Engineering Education (TIDEE) consortium was originally formed with NSF funding to provide leadership in lower-division design education[3]. TIDEE is "a*n interdisciplinary community of engineering design educators committed to developing, implementing, and refining processes which lead to measurable improvements in the readiness of our graduates for team-based design in the modern workplace.*" Over the last eight years TIDEE has provided regional leadership in design education that has resulted in:

- **Consensus** on:
  - attributes of a quality engineer
  - learning outcomes associated with design
  - performance criteria at critical points in engineering degree programs
- **Best practices** for:
  - designing curriculum for engineering design
  - creating assessment tools
  - facilitating student growth in professional skills
  - measuring student performance in a team-based design environment
- **Collaboration** across disciplines and institutions that promotes:
  - new knowledge about engineering design
  - new pedagogical processes
  - materials that enrich design education

Based on feedback by collaborators across the northwest, TIDEE established three goals for its work in design education:

(a) To articulate a set of universal design education outcomes for all levels of the undergraduate education experience,
(b) To create tools for assessing the effectiveness of design learning accomplished via different instructional approaches found in community colleges, four-year colleges, and research universities across the region, and
(c) To create instructional materials that help students master knowledge and skills necessary for effective design team performance.

Learning Objectives for Design Education

Out of faculty workshops and focus groups, TIDEE identified three types of learning outcomes for design courses: (a) design team knowledge, (b) design team processes, and (c) design products[4]. Design team knowledge includes understanding of design team terminology, concepts, and relationships among design team actions and results. Design team processes are the steps engineers utilize to create desired design products. Design team processes include professional attitudes, self-awareness when design steps are executed, and self-control of transition between design steps. Design products are the items created as a result of a design activity—new materials, objects, components,

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systems, documents, or processes to meet specified needs.

From 1995 to 1999, the TIDEE consortium conducted over two dozen faculty workshops to train faculty in creating design activities and facilitating team learning. By consensus of workshop participants, design was conceived as an iterative process leading toward solution of a stated problem or client need. Distinct elements of design were recognized as information gathering, problem definition, idea generation, analysis and evaluation, decision making, implementation, and process improvement. This architecture is consistent with the Professional Decision-Making schema by Wales et al.[5] and the McMaster Problem Solving program by Woods et al.[6]

Figure I illustrates the role of different learning outcomes shifts at different stages of an engineering degree program. First-year students need to gain foundational understanding of design team terms, concepts and processes through participation in guided-design experiences. Although first-year students also will produce design artifacts, these are of lesser importance at this stage. Focus for students in their mid-program years needs to be on refinement of design team processes supported by less prompting, while progressively giving more weight to design product quality. Students nearing completion of their engineering degrees should be self-motivated to improve their design team skills and their focus should be on creating products that meet client requirements.

Separate activities can be found in the TIDEE curriculum archive for beginning, mid-program, and capstone design students. Learning objectives and instructional strategies for design-based activities at different levels of the curriculum are responsive to changing learner needs for design team knowledge, design team processes, and involvement with design products.

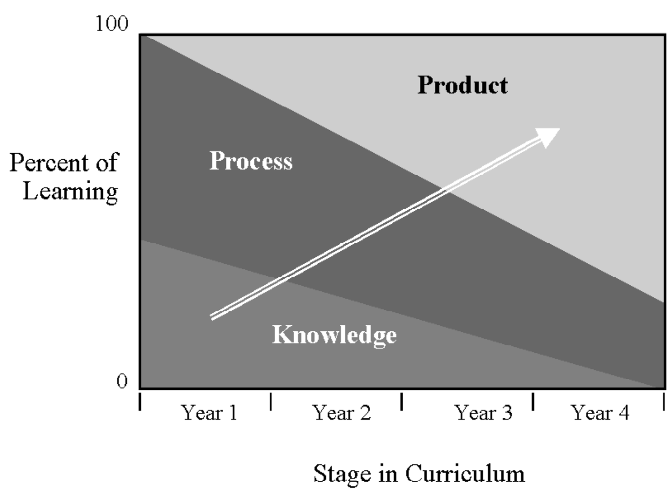

Figure I. Shifting Focus of Design Education

A common element of design education is awareness of elements of design team

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performance, application of procedural knowledge, and progressively more complex metacognition about present and past iterations. TIDEE curriculum promotes awareness of quality factors that underlie design team performance such as those given in Figure II. These fall in three areas: effective design process, effective teamwork, and effective communication. Rubrics distinguishing novice, intern, entry-level, and professional-level performance have been written for each area[4]. The performance factors are consistent with the creative problem-solving model described by Lumsdaine et al.[7] and the project-based introduction to design by Dym and Little[8]. The teamwork attributes are consistent with the cooperative learning model by Johnson et al.[9] The communication attributes are consistent with recommendations by the writing across the curriculum movement and summarized by Bean[10].

Knowledge of the Engineering Design Process

- information gathering/understand problem/customer needs
- problem definition/goals or requirements defined
- idea generation/brainstorming/creativity
- evaluation/analyzing ideas/testing/design modeling
- decision making/selection/planning
- implementation/produce/deliver design to customer
- process review & improvement/iteration

Knowledge of Effective Teamwork

- purpose/goals/focus
- team leader or shared leadership
- assigned responsibilities/accountability
- team attitude/support/commitment
- team member skills/resources/knowledge
- communication/listening

Knowledge of Effective Communication

- clarity of ideas/word use
- organization/logical order
- presentation/format/style/speech
- thoroughness/examples/visual aids
- relevant to audience background/needs
- accuracy/reliability/credibility
- listening/responsive/eye contact

Figure II. Key Attributes of Quality Design Team Performance

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Instructional Strategy for Design Education

Three central features of the TIDEE curriculum support flexible use in a variety of classroom and institution settings. These features include:

1. Structured collaborative learning activities
2. Balanced attention given to design processes and design products
3. Assessment components embedded in nearly all activities

TIDEE design activities use cooperative learning to accelerate development of cognitive, interpersonal, and affective skills. In most cases an inductive approach (beginning from concrete experience and proceeding to theoretical conclusions) is favored over a deductive approach (beginning from theoretical principles and applying them to physical situations). This instructional strategy is consistent with developmental models for young adults[11]. Numerous activities include instruments such as the Hermann Brain Dominance Model, Myer Briggs personality indicator, or the Kolb learning style inventory to generate awareness of students' strengths and how these can be coupled with talents of others to enhance design team performance.

A variety of curriculum materials have been generated to support the development of working expertise in the field of design. They begin with a wide variety of structured design experiences for introductory engineering design classes. Students engage in multiple design cycles that progressively increase in complexity. TIDEE curricula build student capabilities in several areas crucial to effective team-based design. Supporting themes for learning activities include:

- Shaping realistic goals
- Creating focused problem definitions
- Developing detailed plans
- Establishing effective timelines
- Assigning operational roles and responsibilities
- Developing professional capabilities
- Using reflection to assess value added through performance reviews
- Developing and engaging in effective client interviews

TIDEE curricula are sequenced in a three-step development cycle that can add value at any point in an engineering program. The steps include: (1) building teams and teaming skills, (2) expanding design competencies in short, structured activities, and (3) challenging student teams to apply their skills in more complex multi-week projects. The first step establishes a culture for cooperation and effective team function. The second develops an operational definition of quality performance and provides strategies and tools for skill improvement. The third step prepares students to practice engineering in a minimally-structured environment with expectations of high-level performance.

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Structured learning activities articulated by activity sheets form the core of TIDEE curricula. Activity sheets have descriptive titles, define learning objectives, enumerate deliverables and criteria for success, outline tasks, and identify resources that support each learning activity. Their recommended placement within design courses and specific class sessions is shown in course syllabi, unit schedules and daily agendas that are made available to both students and faculty. Instructor guides contain alternative ideas on setting up and bringing closure to these activities. Each activity has set time limits to help keep teams focused on the process and move forward.

For example, the following back-to-back sample activities, "Killer and Igniter Phrases" and "Refining Sounds of Effective Teams" illustrate how TIDEE activities develop and reinforce effective team communication skills. Only the "Igniter Phrases" portion of the activity is shown in Figure III. It is used immediately after its negative counterpart, "Killer Phrases." The "Killer and Igniter Phrases" activity is immensely effective in changing the culture of the classroom to focus on positive communication skills. It is not uncommon, after this activity is used, to hear a student remark, "Please rephrase that into an igniter phrase." Students often list this activity as one of the most valuable activities for the development of skills, engaging in projects or understanding design processes.

Igniter Phrases

Learn to use phrases that will create a positive environment to support the team's activities.

Ø Tasks

- **Team brainstorms for "igniter phrases."**
- **Identify at least 20 "igniter phrases."**

Ø Deliverables

- **Team reporter presents orally:**
- **Number of "igniter phrases" identified**
- **Most effective phrase to help create a positive team environment.**

Ø Criteria for Success

- **Team members listen and build upon each other's comments**
- **Class begins to understand how positive communication can affect team performance**
- **The class's culture shifts towards positivism and support**

Ø Resources

- **Handout: "Killer & Igniter Phrases"**
- **Three minutes of brainstorming time**

Figure III. Igniter Phrase Activity

The activity in Figure IV, "Refining Sounds of Effective Teams," further develops the classroom and team culture by modeling how to effectively communicate when performing

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one of the TIDEE designated team roles.

Refining Sounds of Effective Teams

Learn how to use positive statements to make the team become more effective

Your team's assigned role for this activity is _______ ______

Ø Tasks

1. **Select roles and place the appropriate nameplate in front of each team member.**
2. **Instructor assigns each team a team role to analyze.**
3. **Review the handout: "Effective Statements for Team Members."**
4. **Discuss if these statements would be statements that would be attributed primarily to each role or could be said by any person on the team.**
5. **For your assigned role, think of two situations where the person in this role would need to communicate ideas or information to the team.**
6. **For each situation, generate positive statements that could be used to communicate this information.**
7. **Brainstorm for negative statements that should not be used in this role for this situation.**
8. **Identify how the person in this role can improve team performance through effective use of statements.**

Ø Deliverables

Team Reporter presents on an overhead transparency:

a. **Two situations with positive and negative statements identified for the assigned role.**
b. **The most effective statement that a person in this role could say that would support the team's goals.**

Ø Criteria for Success

- **Statements are constructive and effective in enhancing team performance.**
- **Members have new phrases they could use to make their job more effective.**
- **Members have a broader understanding of the team job responsibilities.**
- **Members have a better understanding of how teaming skills contribute to the success of the project.**

Ø Resources

- **Handout that lists effective statements for team members.**
- **Team member's experience in teamwork.**
- **Fifteen minutes of team discussion time.**

Figure IV. Refining Sounds of Effective Teams Activity

The role of the faculty member in implementing TIDEE curricula is very different from the traditional lecturer model. Most students in TIDEE courses agree that the role of the faculty member in the TIDEE classroom should be "to facilitate success by managing activities to optimally develop students' abilities in the design process."

Faculty development workshops have been offered to promote and enhance faculty members' facilitation skills for more student-centered and team-centered instruction. In

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addition, the TIDEE web site offers tips for effective implementation of many of the TIDEE instructional materials. The tips and techniques are especially valuable for faculty members who are first-time users of the curriculum. It provides support for developing and improving their facilitation techniques and for creating a dynamic teaching/learning environment. The tips and techniques are especially helpful for faculty members who have limited experience in collaborative learning.

Role of Real-Time Assessment

Assessment plays a pivotal role in improving learning performance[12,13]. This includes identifying areas where growth is needed, setting performance criteria, establishing performance goals, measuring performance, and reporting results in an assessee-friendly manner. TIDEE curriculum materials introduce a special team member role: the reflector. This individual actively participates in learning activities, but also regularly reports on team strengths, areas for improvement, and insights about the processes being used. Ideally, strengths are accompanied by explanation of why they are significant, improvements are accompanied by a plan for implementation, and insights are framed in a way that they can be used in new contexts. Other formative assessments such as one-minute papers, peer review, individual and team interviews, student self-assessment surveys, and reflective growth papers, can also be found in this section, each with its unique strengths for different learning objectives and alternative teaching methods. Examples of typical summative feedback received from students engaged in TIDEE structured learning are provided in the appendix.

Website Organization

TIDEE's toolkit for improving engineering design education provides easy user access to resources for all levels of design education. Included in the main menu are:

- Design Process Overview
- Classroom Materials
- Instructor Guides
- Assessments
- Faculty Development/Resources

The **Design Process Overview** provides the user: (a) a definition of the elements of the TIDEE design process, (b) a PowerPoint presentation illustrating how the elements of the design process relate to activities in a short structured design process, (c) explanation of how learning styles affect team process, and (d) instructions for developing quality teams and team processes.

The **Classroom Materials** section contains course designs and learning activities for high

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school summer camps, freshman seminars, sophomore/junior design courses, and capstone design experiences. This includes modules for enhancing team formation, short structured design projects and multi-week guided projects. The team formation and short structured design projects are suitable for any level of design. Each course package contains detailed agendas, learning activities, detailed tips and techniques for effectively facilitating TIDEE activities, and supporting documents that provide background material for students. TIDEE classroom materials can be collated so they can be distributed to students as units of study.

The **Instructor Guides** section discusses (a) course planning and implementation, (b) time frames, (c) activity design, (d) adaptation for different learning styles, (e) collaborative learning, (f) assessment practices, (g) facilitating team development, (h) structured processes, and (i) other resources.

The **Assessment** section features the Design Team Readiness Assessment (DTRA) which measures mid-program design competencies[14]. It consists of three components. The first component is a set of short-answer constructed response questions that assess students' basic knowledge about the design process, teamwork, and design communication. The second component is a team performance assessment that requires students to identify customer requirements and to develop appropriate test procedures for a common hand tool. Teams produce written documentation that reports on team organization, design requirements, relevant test procedures, and actions taken at each stage in the design process. A reflective essay constitutes the third component and provides insights about design team decision-making, team performance, and individual contributions. Respondents are expected to provide evidence of thinking at the awareness, comprehension, and application levels in Bloom's taxonomy. Detailed reliability and validity studies of the DTRA have been reported by McKenzie et al.[15]

The **Faculty Development** section summarizes workshop offerings and publications/presentations given by TIDEE faculty members. Materials have been delivered and refined in a variety of regional and national venues. Workshops have proven effective for first-time users of TIDEE curriculum materials and assessment instruments.

Conclusions

In summary, effective design education uses an iterative, increasingly complex set of team building and design activities to develop the knowledge and skills needed for team-based design. Students are given increasing responsibility and challenged with increasing performance expectations. Students also are increasingly engaged in reviewing performance criteria, applying assessments to themselves and peers, and refining performance criteria. This assessment is embedded in the learning of team and design skills. This approach creates students who are prepared for self-directed use of communication, teamwork, and design methodologies.
TIDEE design curriculum materials have been tested in widely varied classroom and

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research environments. Introductory classes in engineering design focus on developing effective team-based design process skills while utilizing the level of technical skills expected in freshmen students. Upper-division design education materials are tailored to students with prerequisite skills in teamwork and communication and who have a deeper understanding of the engineering design process. TIDEE curriculum materials have also been found effective for college sophomores and juniors, for women and under-represented minorities in high school summer camps, for 5th and 6th graders in conjunction with Society of Automotive Engineer's (SAE) World in Motion, and for a college physical science class using an inquiry approach.

In multiple contexts, TIDEE materials and methods have had the following impacts:

- Faculty members become facilitators, encouragers, and enablers, not just lecturers
- Students make significant gains in their team-based design knowledge and skills
- Assessments empower students to take charge of their learning by setting significantly higher goals and achieving those new standards
- Team synergy produced among students provides support and develops cohorts, which is particularly valuable in retention of underrepresented classes of students
- A growing community of TIDEE collaborators is working together to enhance instructional materials and assessments for engineering design education

If you would like to be part of the TIDEE team, please visit and contact us through TIDEE's website: www.tidee.cea.wsu.edu .

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Ken Gentili is a faculty member at Tacoma Community College, has been a TIDEE PI and curriculum project leader since its inception. Ken is a master teacher in engineering and physics, has created numerous new classes based upon TIDEE philosophy, has developed critical thinking assessment tools, and is an effective workshop facilitator.

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APPENDIX – Common Feedback about TIDEE Curriculum and Teaching Methods

STRENGTHS: Cited in multiple TIDEE activity implementations

We were amazed that we achieved nearly all of the course outcomes. This list seemed so abstract and overwhelming on the first day of class.

Instructor and upper-class mentor were experienced in playing the role of coach. They were helpful without telling us what to do.

Hands-on aspect of class activities—with teamwork rather than just team principles and with product realization rather than just design theory—made for a great experience.

The design projects challenged us to use all the tools and skills we developed earlier in the course. Our understanding how to apply these was moved to a higher level and teaches you how to implement your knowledge.

The reflectors insights let everyone understand the different processes groups went through as they accomplished the tasks given to them and thus provided them with how to improve the team process and create better designs.

This class was a privilege for me. I'm not a very good speaker, but learned to speak with ease before the class due to the support of my team members.

This class represents teamwork to the finest. I really liked the fact that the teams were selected to include diversity of learning styles, which resulted in more creative project results.

This class was by far one of the best that I've ever taken and look forward to follow up classes like it.

AREAS FOR IMPROVEMENT: Addressed by ongoing curriculum review/refinement

Give more elaborate homework assignments so that we can better prepare for class.

Better integrate this class with the engineering graphics curriculum.

Introducing the Gantt chart earlier could have helped the first team project.

Rely on web and email even more for class communication, reducing need for handouts.

Consider having past students give testimonials about the purpose of the course and the personal value in their academic careers.

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The TIDEE design process was well explained and thus there was no need for improvement.

It is important to form a team that is able to have meeting times where everyone can meet outside class. Teams need to make policies to protect against people who don't show up or don't contribute to the process.

INSIGHTS: Indication that deep learning has occurred

Value group meeting times. Have a plan. Regularly review your progress and assign action items with clear accountability.

Address team conflicts early. They won't go away.

Avoid the temptation of complex designs. Keep it simple, adding features based on well-defined needs not just because you think they are cool.

Test your ideas. Compare results with math models as well as competitors.

This class was very effective in teaching us methods of working in a team environment and allowed me to learn the essentials for creative problem solving.

After taking this class I have a greater understanding of people, how to work more effectively with less conflict and how the diversity of people can contribute to create a better design.

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