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Using the Design Process for Curriculum Improvement

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Abstract

This paper describes the process that was used to review and improve the Mechanical Engineering curriculum at Penn State University. The improvement process applied design methodology to review the present curriculum, develop alternate curriculum models, and evaluate those models. The curriculum models that were developed and challenges in implementing this process are also described.

Introduction

The B.S. Mechanical Engineering program at Penn State graduates approximately 230 students each year. The forty full-time equivalent faculty in Mechanical Engineering teach the ME courses and are also expected to be active in research in their area of specialty. Approximately 60% of the students in mechanical engineering start at University Park while the others start at one of eighteen campus locations. Since required courses in the program must be available at all campus locations, the Penn State curriculum can not have specialized mechanical engineering courses in the first two years. The B.S.M.E. curriculum contains 137 semester credits. This is one of the highest degree credit requirements at Penn State and one of the highest for B.S.M.E. degrees around the country.

The Department of Mechanical and Nuclear Engineering (MNE) at Penn State has been heavily involved in curricular improvement, both in the college and in the department. College-level programs such as the NSF-funded Engineering Coalition of Schools for Excellence in Education and Leadership (ECSEL), the Learning Factory, and the Leonhard Center for the Enhancement of Engineering Education have benefited from the involvement of MNE faculty in leadership positions. These organizations have inspired several department-level demonstration projects that have been highly successful. Through these initiatives, cost-effective ways to incorporate active learning into MNE courses have been developed, with demonstrated improvements in student learning. The faculty has observed benefits from active learning components in the knowledge and interest that students display in their courses and in engineering in general.

Motivated by a number of factors including the new ABET Engineering Criteria 2000 (EC2000) and feedback from our industry advisory committee, the department is currently working to incorporate and implement these teaching innovations across the curriculum.

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Although courses and teaching methods are updated and modified, a major change in the B.S.M.E. curriculum has not been made since the mid 1980's.

A formal process has been implemented by formulating the curriculum improvement as an engineering design problem. This paper will describe how design methodology was used in curricular improvement. Following a design methodology created a structured approach to curricular improvement. Design methodology requires that multiple solutions be developed and analyzed before a final selection is made. This allowed all faculty members to participate in a series of discussions and decisions during the process. The steps in the design process are:

- Identify Need,
- Define Problem,
- Generate Alternative Solutions,
- Analysis and Feedback,
- Winnow,
- Detailed Design,
- Test and Refine, and
- Implement.

Identify Need

Previous experimental courses in the department have integrated active learning components into lecture courses. Department-level initiatives include industry-sponsored capstone design projects, the hands-on Integrated Design, Engineering, and Life Skills (IDEALS)[1] course incorporating team design and building projects, the Case Study Web Site[2] that incorporates experimental data analysis into core lecture courses, and the Energy Systems Laboratory[3] used in several required junior courses to demonstrate the integration of analysis from different courses within one application. Course enhancement efforts have been developed by many faculty members in the department. These activities include a computer simulations component in the fluid mechanics lab with an online tutorial, interactive computer analysis during class in the vibrations course, integrated lectures and laboratories in control systems, and an added CAD component to the components design course. Through these initiatives, cost-effective ways to incorporate active learning into MNE courses have been developed, with demonstrated improvements in student learning. The faculty has observed benefits from active learning components in the knowledge and interest that students display in their courses and in engineering in general.

The positive student feedback from previous curriculum innovations has created an interest in providing similar experiences to all students in our undergraduate ME program. The Industry and Professional Advisory Committee (IPAC) for the MNE department also supports the increase of active learning in the curriculum. The positive impact of active learning on a student's education is supported by findings at other institutions and is documented in the literature.[4]

Define Problem

This step can be divided into three substeps: gather information, define objectives, and form an action plan.

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Gather Information

Detailed information about the current ME program was collected as part of the EC2000 review in Fall 2002. A thorough assessment of our program was also conducted. In the program assessment, input was obtained from students, alumni, industry, and faculty. Student performance in all required ME courses was assessed. An Alumni Survey gave us input on the preparation our program provides. Discussions with leaders in industry also provided input to the program.

The program assessment demonstrated the overall strength of our program. It also showed some areas where the program can be improved. Areas for improvement included a better integration across courses, increased design experiences particularly in the thermal sciences, and better integration of computer skills throughout the program.

Define Objectives

Through numerous discussions in faculty meetings and curriculum committee meetings, objectives for the design of a new curriculum were formulated by the faculty in Spring 2003. Initially the design objectives were listed without grouping. It was found that the objectives were more easily conveyed and understood when grouped into two main objectives. These objectives are:

1) IMPROVE DELIVERY - To encourage deeper student learning by:
    a. Integrating theory with practice
    b. Integrating concepts across courses
    c. Requiring fewer courses/semester to increase depth
    d. Enhancing lifelong learning skills

2) ENHANCE CONTENT - Increased student exposure to:
    a. New and emerging technologies
    b. Professional skills (societal impact, ethics, team skills, project management, global issues, economic justification)
    c. Computer and numerical skills
    d. Design methodologies and tools

Each of these objectives is described in more detail below.

1.a. Integrating theory with practice. Integrate classroom material with related laboratory experiments and other active learning elements to improve in-depth learning. This can be done by structuring the curriculum into four-credit courses: three credits of lecture and one credit practicum. Components of the current stand-alone laboratory courses can be folded into the lecture courses. The practicum can also include computer simulations and team projects.

1.b. Integrating concepts across courses. Better integration of the content among core courses is needed. Courses should be designed so that subsequent courses apply and build upon the theory and analysis tools learned in previous courses. This includes a better integration of computer analysis methods across the required courses.

1.c. Requiring fewer courses/semester to increase depth. In the current curriculum students may take up to seven different courses in a semester and up to six different engineering/technical

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courses in a semester. Students have commented that it is very difficult to balance their studies in that many courses. Studying for midterms and final exams can especially be difficult. In addition, group projects might be assigned in several courses and often come due at the same time near the end of the semester.

1.d. Enhancing lifelong learning skills. In the current industry environment, technologies are changing rapidly and a practicing engineer must adapt by learning the new technologies. It is important that the students graduating from our program have the skills required to seek answers and learn on their own. An engineer's education must continue throughout his or her career.

2.a. New and emerging technologies. Give students increased flexibility to focus elective courses or pursue a minor in areas important to the current industry needs: MEMS, nanotechnology, biotechnology, automotive, fuel cells, health science, etc. One way to increase the flexibility in the curriculum, for example, is to reduce the number of required ME core courses and create a four-credit advanced engineering course option. Some topics currently being considered for the advanced engineering course include Manufacturing for Designers, Mechatronics, and Energy Systems.

2.b. Professional skills (societal impact, ethics, team skills, project management, global issues, economic justification). Currently these topics are primarily covered in senior level courses. One objective of the curriculum changes is to better integrate and develop these skills throughout the curriculum.

2.c. Computer and numerical skills. Students are required to take CMPSC 201, a programming course in sophomore year that is taught using C++ or Fortran. No course in the later years of study requires the use of C++ or Fortran. Students are usually allowed to choose the solution method in other courses and often use EXCEL or Matlab. As we review our curriculum and decide on changes, we will also determine what computer skills are important for our students to know and structure the content of courses so that students develop these skills to solve more complex problems in later courses.

2.d. Design methodologies and tools. The program assessment showed that more emphasis should be placed on design methodology. A particular focus will be on strengthening the design component in the thermal science courses. A new junior-level introductory design course was considered to give students an understanding and experience of the complete design process. This junior-level design course would be a prerequisite for all senior-level design courses.

There are also several constraints present in designing a new curriculum:

1. Minimal change in first two years (at least in this phase). At Penn State, students enter as engineering students and do not declare a major until second semester of sophomore year. To give students the flexibility to learn more about different majors and their interests, it is advisable to follow a standard engineering program in the first two years and not require ME courses.
2. Workable transition plan. After changing to a new curriculum, there will be some students following the old curriculum. There needs to be a plan for accommodating these students who entered under the old curriculum. There are two options: continue to offer limited

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sections of the old curriculum courses, or allow substitutions of the courses in the new curriculum.

3. Reasonable faculty work load. Assuming that the faculty size will remain constant, the total teaching load for the new curriculum must be similar to the old curriculum.
4. Reasonable student work load. Students must not have an increased work load in the new curriculum.
5. Availability of sufficient department resources for successful implementation. Any curriculum changes need to be financially feasible.
6. Some reduction in overall credits. At 137 semester-credits, the B.S.M.E. degree has one of the highest credit requirements across degrees at Penn State and across B.S.M.E. degrees nationwide.

Action Plan

During the academic year 2002-2003, discussions were held at every MNE faculty meeting to draft the objectives of curriculum changes. In Spring 2003, eight faculty worked in a committee to formulate the process that will be used for curriculum improvement. As ideas were formulated and presented in faculty meetings, more faculty members added their support for curriculum improvement and indicated their interest in participating. One continuing message expressed by faculty members is that they want the curriculum improvement to improve student learning, not only reduce the number of credits required for graduation.

The Professor-in-Charge of Undergraduate Programs in MNE, Laura Pauley, and the Department Head, Richard Benson, oversee the curriculum improvement process. Due to the large scope of the proposed curriculum changes, a Coordination Team was created to coordinate the effort. The Coordination Team includes John Lamancusa, Tom Litzinger, and Laura Pauley. The Coordination Team identified five primary course areas in the mechanical engineering curriculum: System Dynamics & Control, Thermal-Fluids Systems, Electronics & Instrumentation, Materials & Manufacturing, and Design. These areas and the courses in each area are shown in Figure 1.

In Fall 2003, Course Sequence Teams were formed in each area of the mechanical engineering curriculum to review the current course sequence and apply the curriculum design objectives in developing a revised program. The Coordination Team selected the membership of each Course Sequence Team to include three or four faculty who have taught the courses in that sequence or are familiar with that area.

Each Course Sequence Team examined the content of each course in the sequence as described in our ABET documentation. Course descriptions were expanded to include topics covered in each lecture and sections of the textbook covered in the course. This level of detail was required in order to understand the depth that topics are studied. The Course Sequence Teams then reviewed the topics and identified each topic as:

- Important content to be retained in a required course,
- Content repeated from a prerequisite course,
- Content appropriate for a specialized options course,
- Legacy material that should be omitted from the curriculum, and
- Additional topics that should be added to the required course sequence.

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The topics were then matched to the program objectives. In cases where the course content could not be matched with a program objective, a discussion focused on whether the course content or program objectives needed to be modified. Each course sequence team was asked to prepare two or three possible new course sequences that better integrated content across courses and reduced unnecessary repetition of course material. All Course Sequence Teams were asked to prepare at least one plan that included four credit courses with a weekly laboratory/practicum session.

The Course Sequence Team in Electronics and Instrumentation was also asked to investigate the elimination of the required statistics course and adding the necessary material to the ME Measurements course, ME 82.

The Design Sequence Team was asked to prepare at least one course sequence plan that included a junior-level design course, numbered as ME 340. Possible topics in ME 340 include:

- Team Skills,
- Project Management,
- Design Process,
- Design Tools (CAD, ProE, AutoCad, QFD, etc.),
- Case Studies,
- Societal Impact & Ethics,
- Economic Constraints/ Budgets,
- Professional Communications, and
- Design Project (paper design).

As each Course Sequence Group developed new course plans, implementation issues were recorded but did not limit the ideas being considered. Each course plan included a detailed list of the course content and active learning components in each course. The course objectives for each proposed course were identified and matched to program objectives.

Generate Alternative Solutions

The Coordination Team conducted benchmarking of other ME programs in the country. All faculty were invited to recommend ME programs that should be studied. Ten ME programs were selected for detailed benchmarking. These institutions included some Big-Ten universities, other large engineering programs, and some smaller programs. The data was summarized, presented at faculty meetings, and posted electronically for faculty access.

Three different curriculum models were found at benchmark institutions. These three models are summarized in Figure 2.

The first model is the structure of the current BSME program at Penn State. Students take lecture courses covering the theory, analysis, and design in a particular area. Hands-on laboratories are scheduled in senior year. In most cases, the laboratory must be taken after the lecture course since students rotate through the lab experiments and may not run the labs in the same order as material is presented in the lecture course. This curriculum model uses the laboratories as a reinforcement of the lecture material.

The second curriculum model integrates lecture and practice into one course by having three lectures and one practicum each week. The practicum sessions usually have a smaller class size

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and may be two or three hours long. The practicum session might include one or more of the following activities:

- examples from real systems,
- in-class demonstrations,
- case studies,
- full laboratory experiments or portable “lunch box” experiments
- product dissection and reverse engineering,
- computational exercises,
- small group discussion,
- problem sessions,
- projects,
- guest speakers and field trips.

The four credit model gives students hands-on, real examples during the course so that the theory from lectures is immediately applied. A possible ME curriculum was developed with a practicum added to four courses: Thermodynamics, Fluid Flow, Vibrations, and Controls.

The third curriculum model contains traditional lecture courses but uses a clinic each semester to integrate material across courses. The clinics can include the same active learning components as the practicum in the four-credit courses. The clinics, however, integrate material across several courses. A proposed model of the ME curriculum was developed with a clinic taken each semester in junior and senior years. The first clinic covers design methodology as described in ME 340 above. The second clinic is taken in the same semester as the Heat Transfer course and integrates material from the three thermal science courses, thermodynamics, fluid mechanics, and heat transfer. Schmidt et al.[5] describe the activities in the thermal sciences clinic at UT Austin. The clinic includes two or three projects in the semester. One project that has been used with good success at UT is the reverse engineering of a refrigerator. One refrigerator is sacrificed for study of the components. A second refrigerator is instrumented to collect data during operations. The students are required to analyze the refrigerator performance and compare to the measured values.

Analysis and Feedback

Meetings between the course sequence teams, faculty meetings, and a focused faculty workshop have been used to evaluate different curriculum plans and develop a final plan for curricular improvement. Course sequence teams reported at each monthly department faculty meeting from November 2003 to March 2004. A focused faculty meeting in January 2004 and retreat in February 2004 allowed for the presentation of course sequence plans and a comprehensive discussion by the faculty. Discussions continued at spring and fall faculty meetings and at a series of Brown Bag Lunches. The Brown Bag Lunches allowed for focused discussions on particular aspects of the curriculum improvement process such as resource issues or active learning.

To guide our efforts, input and comments on our current program and proposed curriculum models were solicited from current undergraduates, MNE graduates, and from the industry advisory board, IPAC. One ME student, Alan Batista, selected the ME curriculum improvement as the topic of a technical writing report in ENGL 202C[6]. Alan talked with other students, created a survey, and administered the survey in an ME senior level course. The results of the

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survey and recommendations for curriculum changes are presented in Alan's report. His findings confirmed many of the objectives and ideas that the faculty had established: reducing the number of courses each semester, better integration between courses, adding a junior design course, and integrating statistics into the ME instrumentation course. Laura Pauley has met with several student groups (ASME and Pi Tau Sigma) to obtain input and suggestions from students.

On March 1-2, 2004, the Industry and Professional Advisory Committee (IPAC) visited the department. The primary focus of the annual review was a discussion of the curriculum and the changes being considered. IPAC members gave a strong endorsement of the curricular efforts and proposed changes. They encouraged the addition of a junior-level design course and a better integration of active learning components the junior and senior years.

In Spring 2003, an assessment of computer skills throughout the program was conducted. All required courses in MNE documented the use of computer methods and student performance. In required courses not taught in the department, a detailed syllabus and information on computer skills taught and used in the course was collected. This assessment showed that the programming in C++ or Fortran taught in CMPSC 201 was not used in later courses. The primary analysis tools used in ME courses were EXCEL and Matlab. It was also found that the use of computer tools is not well coordinated through a sequence of courses. These findings resulted in the addition of Objective 2c in the curriculum improvement.

Winnow

To decide which curriculum model will be adopted, each model has been studied in detail. The required resources to implement each model have been identified. Resources considered are facilities, faculty, and graduate student or technician assistance. There is a deep concern over the resources needed for a substantive change. We are considering fundamental changes in how we teach, and many faculty are not convinced that this change is necessary, or is worth their time which can be devoted to other things which are more rewarded in the university system.

Currently the department has specialized laboratories in fluid mechanics, heat transfer, vibrations, and controls. In both curriculum models, these existing laboratories will be used. In either proposed curriculum model, other facilities will be needed for product dissection, reverse engineering, computational exercises, and integrating projects. Some facilities currently exist at Penn State through the Center for Engineering Design and Entrepreneurship (CEDE)[7]. Photos of some available facilities are shown in Figure 3. Since the facilities are shared by all departments in the engineering college, we may find that some heavily used facilities will need to be duplicated within the department.

To engage students in the active learning components, many of these activities will be taught by a faculty member. A detailed faculty teaching load analysis has been conducted with the model of 60 students in lecture sections and 30 students in practicum or clinic courses. It has been shown that faculty teaching loads will not increase if graduate teaching assistants are used for 1/3 of the practicum or clinic meetings to run laboratories. Faculty would be present during more open-ended activities of product dissection, computer applications, and projects.

As the Spring 2004 semester came to an end, we were continuing to work on the winnow step. The original timeline we drafted listed the selection of a curriculum model by the end of spring semester. The process of discussion and building faculty consensus had taken longer than we first expected. Although Course Sequence Teams worked in Fall 2003 and reported on team

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discussions at each faculty meeting, some faculty members did not begin to seriously consider the changes until the retreat in February 2004. Attendance at the retreat was very good and this was the first time that nearly all faculty members were present at one meeting to discuss alternative curriculum models. Since not all faculty members were able to attend every faculty meeting, it was found that electronic posting of Powerpoint presentations and detailed meeting minutes allowed everyone to keep up with the discussion. Comments were collected at the retreat, typed, and distributed to all faculty members. A faculty survey also provided helpful input by showing areas of consensus and areas where there were varied opinions. Openness to all comments and a willingness to adjust the process to respond to faculty concerns has been important.

At the end of Spring semester, the faculty considered the four credit course model to be well defined but there were still questions about the content of the clinic courses. During the Summer 2004, three faculty designed possible course outlines for Design I and the clinic courses. This was done so that faculty would better understand the content and format of the clinics. This level of detail was necessary for faculty to make an informed decision. The sample clinic courses were presented at the September 2004 faculty meeting. During the discussions, it was clear that there were still questions and concerns about resources and implementation of the practicum or clinic models. Reaching faculty consensus on the most promising curriculum alternative has been challenging. In a faculty as large and diverse as ours, this is expected to be a contentious process, involving both facts and emotion. Decisions will ultimately be based not only on how well the alternatives meet the original design objectives, but on each faculty member's comfort with change, and his/her personal cost/benefit analysis. Our experience to this point has shown that it is important to inform faculty of the details of implementation and to allow faculty to learn from the experiences of others. On many occasions, the discussion strayed from direct discussion of different curriculum models to a discussion of faculty experiences teaching in different formats. Although this has increased the timeline for the curriculum changes, these discussions are essential in building the comfort of faculty to implement curricular changes. Two Invited Speakers, Phil Schmidt from Texas Austin and Sherra Kerns from Olin College, presented seminars on curricular innovations at their institutions.

During the discussions in September and October, consensus could not be reached on the clinic or practicum models. But there appeared to be support for a junior design course and integrated statistics with the instrumentation course. In October, a paper ballot vote was distributed for two curriculum changes:

1. Eliminate the 3-credit statistics course and change the 3-credit Instrumentation and Measurements course to a 4-credit course that includes statistics.
2. Add a 3-credit junior-level design course to the curriculum. The design methodology material taught in the senior design course would be moved to the junior course, thus reducing the senior design course from 4 credits to 3 credits. The junior design methodology course will be taught in classes of 30 students. To balance the faculty teaching load, two junior level lecture courses (Machine Dynamics and Thermodynamics II) were removed from the curriculum.

These curriculum changes were approved by the faculty in October 2004. The changes did not increase the teaching load for the ME faculty. The changes reduced the ME curriculum from 137 credits to 131 credits.

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Detailed Design

The Course Sequence Teams in Electronics & Instrumentation and Design prepared course proposals for the revised Instrumentation course and the junior-level design course. These course proposals were presented to the faculty at the January 2005 faculty meeting.

After the new curriculum has been defined, each Course Sequence Team will prepare a Learning Plan that shows the development of computer skills and learning skills through the sequence of courses. In each Learning Plan, there will be examples of course activities, projects, and assignments that will develop these computer and learning skills. As the Learning Plan is developed for each course sequence, the content of the sophomore level programming course, CMPSC 201, will be reviewed. It might be decided that CMPSC 201 be developed into an introductory course of computational methods that are used in later classes. The content of the required chemistry and mathematics courses will also be reviewed to assure that the needed prerequisites are taken. The Speech Communication course, CAS 100, will also be studied to determine the effectiveness of the course for engineering students.

During Spring 2005, Teaching Forums will be presented in the department. The format of most forums will include a short presentation by MNE faculty or an invited speaker followed by open discussion. Possible topics include:

- Student learning styles,
- Incorporation of higher level learning skills in classes,
- Effective and appropriate use of student teams,
- Development of skills through a course sequence (e.g. computer skills),
- Assessment of student learning,
- Definition of design?
- Appropriate use of technology in the classroom.

The Teaching Forums will give faculty the ability to add higher level learning components and active learning to their courses and to evaluate the effectiveness of these components.

Test and Refine

A pilot section of the junior-level design course is being offered in Spring 2005. The course will be assessed and modified in Summer 2005. Two sections of the course will be taught in Fall 2005. Students who enroll in the pilot classes will be permitted to substitute the credits for requirements in the current curriculum so that they can continue normal progress towards graduation. A workshop is being planned in Summer 2005 to allow other faculty members to learn from the pilot section of the design methodology course and to also learn methods for teaching a design course.

Implement

We plan to implement the new curriculum in Fall 2005 for all B.S.M.E. juniors at Penn State. The change to a new curriculum required that a curriculum proposal be written and approved by the ME faculty, by the College of Engineering, and by the University Faculty Senate. The same procedure is required for every new course in the new curriculum.

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Assessment of curriculum changes will be conducted with the assistance of Engineering Instructional Services. The assessment data will be used to refine the courses prior to a second offering.

The discussions on active learning across the curriculum will continue next year. One pilot study planned for Fall 2005 will develop and test take-home experiments in several junior-level lecture courses. Another pilot study will synchronize the current laboratory courses with the lecture courses so that students can take the two courses concurrently. These curricular experiments will be assessed and considered for implementation. Other components of the curriculum will be assessed and possibly modified in future years. As described by the new ABET guidelines, curriculum assessment and improvement will be an ongoing process.

Conclusions

A design methodology process has been used to develop a new curriculum in mechanical engineering. The design methodology has given structure to the difficult process of curriculum improvement. Since most faculty members are familiar with design methodology, the use of this process gives some level of comfort in working on the new challenge of curricular change. The design methodology has also required that the process be conducted in a well informed way. Developing detailed curriculum models, analyzing the feasibility of each, and comparing with existing curriculum models at other institutions are required steps in this process. Without the structured design methodology, it is easy for the process to be based on personal impressions and preferences.

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Biographical Information

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THOMAS A. LITZINGER is currently Director of the Leonhard Center for the Enhancement of Engineering Education and a Professor of Mechanical Engineering at Penn State, where he has been on the faculty since 1985. His work in engineering education involves curricular reform, teaching and learning innovations, faculty development, and assessment. He received his Ph.D. from Princeton University in 1986. He may be contacted at tal2@psu.edu.

Figure 1. Primary course areas and organization of curriculum improvement process.

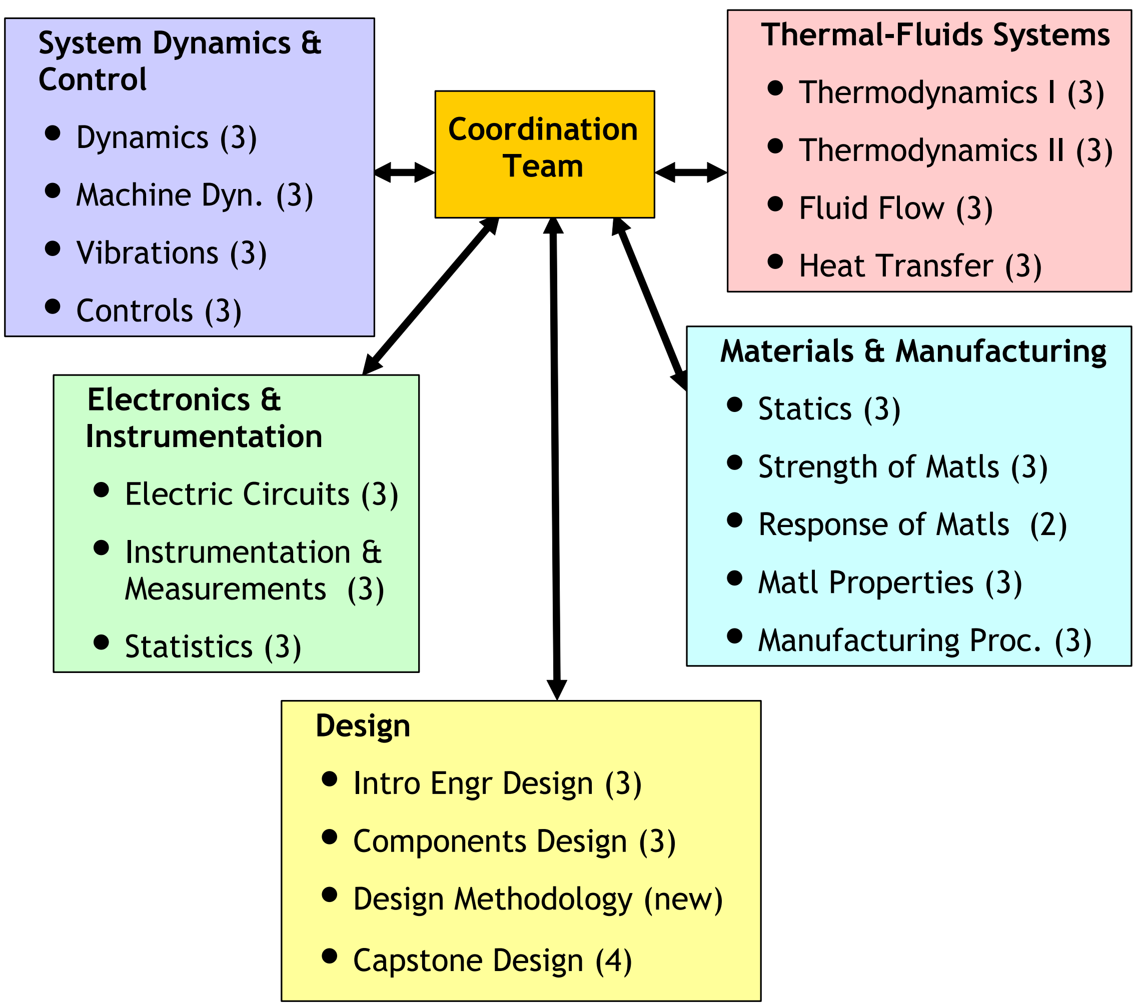

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Figure 2. Three Curriculum models.

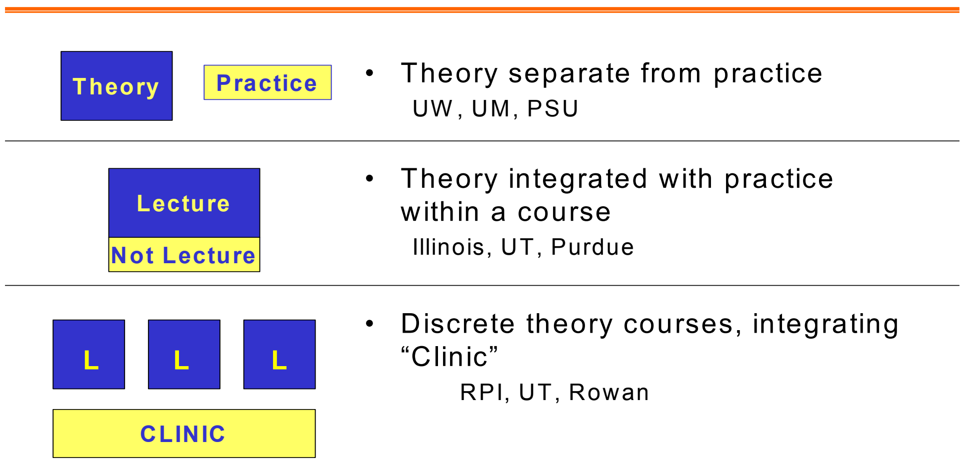

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Figure 3. Facilities at Center for Engineering Design and Entrepreneurship (CEDE) include Model Shop, Design Studios, Computer Classrooms.