ENGINEERING COURSE DESIGN

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1. Good Teaching

Good teachers want good learning to occur as a result of their teaching. Good learning means, besides recalling information, the ability of problem solving, critical thinking, and creative thinking. Good learning is also referred to as meaningful learning, significant learning and/or higher orders (Apply, Analysis, Evaluate and Create categories of Bloom's taxonomy) of learning. Fink (L.D. Fink 2003) identifies four components of teaching depicted in the figure 1.

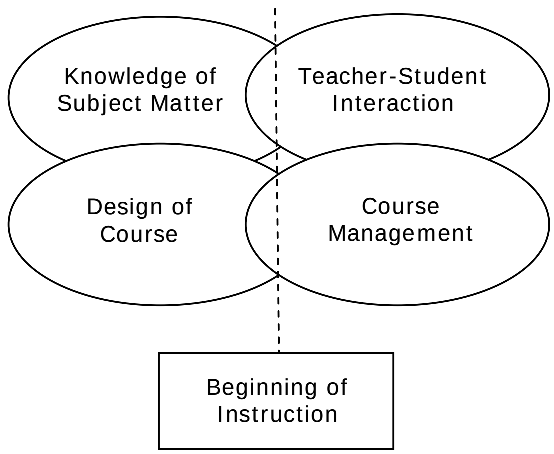

Fig. 1: Four components of teaching

All teachers need to have adequate knowledge of the subject matter, design instruction of their course (Course Design), interact with students, and manage course events. The first two in general take place before the course begins; the other two after it begins. This view implies that a teacher can improve his/her teaching leading to good learning by students by improving any or all of the four competencies. However, the impact of improvement in their competencies on learning by the student may not be equal. For example knowledge of subject matter is not a major bottleneck for good teaching, as teachers are hired for having the requisite knowledge. Still a teacher can improve her knowledge of the subject from the many resources available.

"Teacher-student interactions" is an umbrella term that refers to all the different ways teachers interact with their students: lecturing, leading class discussions, tutoring, meeting with individual students, communicating by e-mail and so on. This aspect of teaching is a skill that runs the full spectrum from poor to excellent. Some faculty members have a personality and a set of social skills that make it easy for them to interact naturally with students in a way that enhances learning. Others need to learn how to be more dynamic, establish better credibility, and otherwise relate better with their students. For a significant percentage of college teachers, learning how to improve their interactions with students would be a major advance. For the others, this is not the primary problem.

"Course management" refers to conducting instructional events of the course in an organized manner. Instructional events refer to conducting the sessions as per declared time table, having assignments ready when they are needed, grading and returning test papers promptly, and so on. In most of the cases course management is not a major problem.

“Course Design” or “Design of Instruction" is a skill for which few college-level teachers have any training, especially teachers of higher education courses. But most teachers simply follow the traditional ways of teaching in their particular discipline which consists of presenting the material in the class strictly as per the selected chapters and sections of identified text books. They require the conceptual tools they need to significantly rethink and reconstruct the set of teaching and learning activities they use. Of these four basic aspects of teaching, faculty knowledge about course design is the most significant bottleneck to better teaching and learning in higher education.

Course design consists of choosing the outcomes the students are expected to achieve at the end of the course, assessment that is in alignment with the chosen outcomes, and planning instructional activities that facilitate students to acquire these outcomes. An engineering course is an element of a program which consists of several courses belonging to different categories like Basic Sciences, Engineering Sciences, Humanities and Social Sciences, Professional Core, Professional Electives and Open Electives. These courses are offered in a specified sequence over eight semesters. An engineering program is required to meet in India set of Program Outcomes as identified by National Board of Accreditation (NBA), India.

One framework for systematic design of a course is known as ADDIE. The ADDIE model, as particularly applied to engineering course design, is elaborated in the following.

2. Instruction

The purpose of instruction is to help people learn and develop. The kinds of learning and development may include cognitive, affective, psychomotor and spiritual. Learning can certainly occur without instruction. We are continuously encountering and interpreting our environment and the events in it. Learning is a natural process that leads to changes in what we know, what we can do, and how we behave. However, one function of an educational system is to facilitate intentional learning, in order to accomplish many goals that would take much longer without instruction. Educational institutions teach knowledge and skills that the community feels are desirable, even if they are not of immediate personal interest to the student, and even if they would not be encountered naturally in non-school environments. The government and commercial industries provide both skills and training and continuing refresher training to help employees acquire the skills and learning needed to succeed in a changing workplace (Gagne et. al. 2005).

Instruction is anything done purposefully to facilitate learning. Is teaching different from instruction? Teaching is only one part of instruction. The word “teach” infers that a person is lecturing or demonstrating something to the learner. However, the teacher or trainer’s role includes many different tasks, such as selecting materials, gauging student readiness to learn, managing class time, monitoring instructional activities, and finally serving as a content resource and a learning facilitator. “Instruction” puts emphasis on a whole range of activities the teacher uses to engage the students. Instruction is more likely to be effective if it is planned to engage students in those events and activities that facilitate learning. Using principles of instruction design, the teacher can select, or plan and develop activities to best help students learn.

Application of principles of instructional design would benefit a number of persons connected with education, including those who are in the business of producing instructional materials, such as textbook writers, curriculum material developers, web-based course designers, and knowledge management system designers.

3. Instructional System Design Model

Instructional Systems Design (ISD) Models are the systematic guidelines instructional designers follow in order to create a workshop, a course, a curriculum, an instructional program, a training session, or the instructional materials and products for educational programs. ISD is a process to ensure learning does not occur in a haphazard manner, but is developed using a process with specific measurable outcomes. The responsibility of the instructional designer is to create learning experiences, which ensure that the learners will achieve the goals of instruction. ADDIE is generic model for instructional system design. All other ISD models can be treated as particularizations or elaborations of this model for specific purposes. For example, the very popular Dick and Carey model (2005) can be seen as one elaboration of ADDIE model for training programs, though the authors did not refer to ADDIE. One particularization of ADDIE model to courses in formal engineering programs is presented in the following.

ADDIE Model: The "ADDIE Model" is a colloquial term used since 1980s, known also as military model of instruction, to describe a systematic approach to instructional development. It is not a specific, fully elaborated model in its own right, but rather an umbrella term that refers to a family of models that share a common underlying structure. ADDIE is an acronym referring to the major processes that comprise the generic ISD: **Analysis, Design, Development, Implementation**, and **Evaluation**. These processes are sequential and iterative, as depicted in figure 2.

The basic engine of ISD models (Molenda 2003) is the systems approach: viewing human organizations and activities as systems in which inputs, outputs, processes (throughputs), and feedback and control elements are the salient features. The iterative aspect of the model is represented vertically down the model by the arrows in both directions between each phase, as depicted in figure 2. Each major phase of the process is accompanied by some sort of formative evaluation, as depicted on the left side of the model, to test the adequacy of the decisions made during that phase. After Analysis, for example, the accuracy of descriptions of the audience, the learning needs, and the instructional objectives to meet the learning needs are evaluated by a group of experts. In the Design phase the assessment pattern, sample assessment items in alignment with competencies and item bank are created. Based on the peer evaluation of design phase outputs, instructional material is developed and learning materials are selected or developed for all instructional units in the Development Phase. After the evaluation of Development Phase outputs the course is implemented in the Implementation Phase, and the efficacy of prototype is evaluated and improvements to the learning materials are worked out. Did the entire intervention achieve its goal, or what remains to be done after Implementation? This summative evaluation is what is symbolized by the final Evaluation phase. At each of these phases, the results of the evaluative activity could lead the developers to revisit earlier steps, hence the arrows between phases in both the directions.

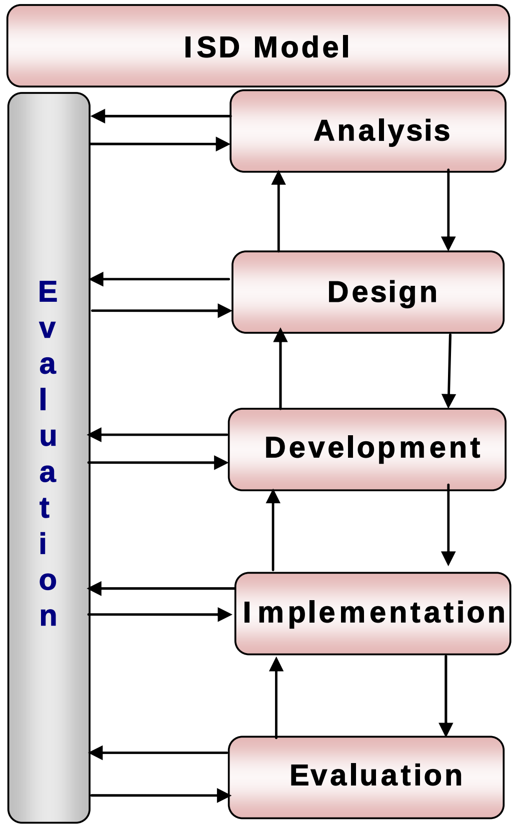

Fig. 2: ADDIE model of ISD

The single most important feature of ADDIE model is the identification, at the beginning of instruction design, of instructional objectives, which we refer to here as outcomes or competencies. The activities under all these four phases will greatly depend on the nature of what is being created and the context in which it is being created. The context is defined by the audience and their background, environment in which the instruction takes place, and the technologies available.

4. Specificity of Instructional Objectives

The general domain of objectives is best represented as a continuum ranging from quite general to very specific. Krothwal and Payne (1971) identify three levels of specificity, along the continuum of general domain of objectives, as global, educational and instructional (guidance) objectives. In case of formal engineering programs of four years duration in India we identify three levels of objectives:

- Program Outcomes and Program Specific Outcomes
- Course Outcomes
- Competencies

Program Outcomes and Program Specific Outcomes: Program Outcomes, as per NBA, are statements that describe what the graduating engineers are expected to know and be able to do. These relate to the knowledge, skills and behavior the students acquire through the program. The Program Outcomes as identified by NBA for all engineering programs are

1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis**: Identify, formulate, research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design/development of solutions**: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
4. **Conduct investigations of complex problems**: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool usage**: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
6. **The engineer and society**: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and team work**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
11. **Project management and finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
12. **Life-long learning**: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

A department should identify a small number (2 to 4) of Outcomes specific its program, known as Program Specific Outcomes (PSOs) in addition to the twelve POs identified by NBA.

In order to achieve equivalence of engineering programs across countries several countries signed an accord in Washington, known as Washington Accord. The Program Outcomes as defined by Washington Accord are also generic and program (Electrical Engineering, Mechanical Engineering etc.) non-specific, and are

1. Apply knowledge of mathematics, science, engineering fundamentals and an engineering specialization to the conceptualization of engineering models.
2. Identify, formulate, research literature and solve *complex* engineering problems reaching substantiated conclusions using first principles of mathematics and engineering sciences.
3. Design solutions for *complex* engineering problems and *design* systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations.
4. Conduct investigations of *complex* problems including design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions.
5. Create, select and apply appropriate techniques, resources, and modern engineering tools, including prediction and modeling, to *complex* engineering activities, with an understanding of the limitations.
6. Function effectively as an individual, and as a member or leader in diverse teams and in multi-disciplinary settings.
7. Communicate effectively on *complex* engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
8. Demonstrate understanding of the societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to engineering practice.
9. Understand and commit to professional ethics and responsibilities and norms of engineering practice.
10. Understand the impact of engineering solutions in a societal context and demonstrate knowledge of and need for sustainable development.
11. Demonstrate a knowledge and understanding of management and business practices, such as risk and change management, and understand their limitations.
12. Recognize the need for, and have the ability to engage in independent and life-long learning.

As it can be seen the Programs Outcomes as stated by NBA are in the spirit of Washington Accord.

Washington Accord particularly emphasizes Complex Engineering Problems and Complex Engineering Activities. These are characterized as

Complex Engineering Problems

- Involve wide-ranging or conflicting technical, engineering and other issues
- Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models
- Requires in-depth knowledge that allows a fundamentals-based first principles analytical approach
- Involve infrequently encountered issues
- Are outside problems encompassed by standards and codes of practice for professional engineering
- Involve diverse groups of stakeholders with widely varying needs
- Have significant consequences in a range of contexts

- Are high level problems possibly including many component parts or sub-problems

Complex Engineering Activities

- Involve the use of diverse resources (and for this purpose resources includes people, money, equipment, materials, information and technologies)
- Require resolution of significant problems arising from interactions between wide-ranging or conflicting technical, engineering or other issues,
- Involve creative use of knowledge of engineering principles in novel ways
- Have significant consequences in a range of contexts
- Can extend beyond previous experiences by applying principles-based approaches

Course Outcomes: Course Outcomes are statements on what the students will be expected to do at the end of the course. The number of course outcomes need to be small in number, around six. These statements start with action verbs like understand, compute, determine, model, analyze, select, formulate, architect, specify, design, build, implement, operate and test.

Competencies: The course outcomes are elaborated, if necessary, into a set of competencies, say 15±5. Competencies are effective abilities, including attributes, skills and knowledge, to successfully carry out some activity which is totally identified. The competencies require a small number (1 to 5) of hours of instructional activities and represent well defined goals. Each competency may be treated as one Instructional Unit.

5. Engineering Course Design in ADDIE Framework

As engineering programs are formal, elaborate mechanisms exist for selection of students to these programs, and the curriculum identifies the course structure and prerequisites of each course, the analysis of audience and entry behaviors need not be undertaken for each course. The time and budget constraints also do not change from one course to the other very much. All courses are of one semester duration and have well defined credit load. Therefore, the major task of the analysis phase is identification of instructional goals/course outcomes/competencies. An engineering program has well defined *Program Outcomes* (POs) as identified by NBA and a small number of *Program Specific Outcomes* (PSOs). Each course attempts to meet a subset of these POs and PSOs. The selected POs and PSOs need to be translated into a set of *Course Outcomes/ Competencies* related to the subject matter of the course.

The stages of *analysis phase* for an engineering course may be listed as

1. Writing the course context and overview
2. Preparing Program Specific Outcomes
3. Writing 4- 8 Course Outcomes as required by National Board of Accreditation (NBA) that can be measured for attainment, and mark them for relevant POs, PSOs, Cognitive Level, Knowledge Categories and the sessions (classroom, tutorial and laboratory) required.
4. Locating the Course Outcomes in the taxonomy table.
5. Preparing Course-PO/PSO matrix (row) of the course
6. Elaborating Course Outcomes into 15±5 Competencies of the course to facilitate instructional planning
7. Having the output of analysis phase peer reviewed and make the changes needed

Design Phase

The design phase represents activities that enable the course designer to generate a plan according to which the instruction would be conducted, and instructional material and learning material would be developed. The stages of *design phase* for an engineering course may be listed as

1. Determine the assessment pattern.
2. Write a minimum of four representative test items for each course outcome at its cognitive level, and sample solutions to these test items that would reflect instructor's way of integrating competencies and selected program outcomes.
3. Create the Item Bank as per the assessment pattern
4. Have the outputs of design phase peer reviewed and modify them if necessary.

Development Phase

The development phase represents activities that convert the blueprints created in the design phase into instructional materials and learning materials. Each competency represents one Instructional Unit. The stages in the development phase of an engineering course consist of

1. Select the delivery technologies proposed to be used.
2. Prepare instructional materials for all Instructional Units.
3. Select and/or prepare learning materials for all Instructional Units for the course.
4. Have the outputs of development phase peer reviewed and modify them if necessary.

Implement Phase

Instructors conduct the course as per the instructional plan prepared in the Design Phase using instruction material and learning material prepared in Development Phase. However, each instance of a course conduct is likely to be slightly different based on the context and the time of offering. Implement Phase presents specifics of an instance of offering. The specific elements of Implement Phase are

1. Syllabus
2. Resources Planning
3. Instruction Schedule
4. Instructor's perception of students with regard to their abilities and motivation
5. Observations on Instruction
6. Additional sessions conducted by the instructor beyond the scheduled hours
7. Student feedback during the session
8. Create sample structures of Assessment Instruments
9. Assessment Instruments
10. Observations on Assessment Instruments and Student Performance
11. Feedback to students after every assessment
12. Tracking students

Evaluate Phase

Instructors conduct the course as per the instructional plan created in the Design Phase using instruction material and learning material prepared in Development Phase. However, each instance of conducting a course is likely to be slightly different based on the context and the time of offering. Implement Phase presents specifics of the instance of offering and involves preparing and communicating the Syllabus of the course, planning resources for conducting the course, scheduling instruction, creating specific assessment instruments, giving feedback to students after every assessment, and tracking the performance of students.

Every instance of course conduct should be evaluated to plan for improvements to the next instance of course offering. The evaluation can be self evaluation by the instructor as well as by peers. The activities of evaluation phase include

1. Student feedback at the end of the course
2. Computing CO and thereby PO and PSO attainment
3. Summary observations
4. Peer feedback
5. Plans for reducing the PO and PSO attainment gap or increasing PO and PSO attainment targets

6. Summary

Design of a course is done in five stages as per ADDIE model. The Analysis, Design, Development, Implement and Evaluate phase activities require an in depth understanding of the present day context and an awareness of different technologies available. The instructor needs to appreciate availability of a large number of instructional methods and learning resources. He has now an opportunity to facilitate students to learn as per his/her view of good learning.

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