A Significant Learning Approach for Materials Education

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Abstract
Higher education, especially in the engineering milieu, is a complex activity. Many different tasks need to be performed well to achieve high quality student learning. Significant learning experiences require specific (and optimal) course design, and inculcation of relevant skills. The more common approach for course design is the 'content-centered' one. A list of topics is decided (using well-established textbook/s), together with time slots and a testing scheme (number of quizzes, tests, etc). Though relatively easy, this methodology pays scant attention to student learning outside of content knowledge. The more time and effort intensive 'learning-centered' approach is more systematic and rewarding. Course design is based on deciding what students can optimally learn in a certain subject, and how to best facilitate this learning. Fink's model of "significant learning" or "integrated course design" has three major components: identification of important situational factors; use of these factors to make key decisions about learning goals, feedback and assessment, and teaching/learning activities; and making sure that these crucial components are well integrated and supplement and strengthen each other.

This work-in-progress paper presents a strategy to use Fink's significant learning approach in materials science and engineering courses in an undergraduate engineering program. Examples and activities are taken from two core courses of the Mechanical engineering program at our university (Materials science, and Engineering materials). This methodology, targeting significant learning experiences, can also be applied to other engineering and science (and even non-science) courses.

Keywords: Engineering education; significant learning; integrated course design; materials science and engineering

Introduction

Modern industry and society are witnessing an ever-increasing role of materials science and engineering (MSE). A variety of engineering materials serve as basic building blocks in different industries. Without modern engineered materials, scientific and technological advancements would not be possible in such diverse fields as automobiles and transportation, construction and structural engineering, aerospace and astronautics, health and medicine, computers and telecommunications, agriculture and environment, etc [1]. Broad areas covered by materials science and engineering include synthesis and processing of materials; structure, composition, and properties; tailoring of material properties; and performance testing and applications. The importance and role of this multi-disciplinary field is becoming even more significant for the current and future world due to increasing concerns about economics and business, new technologies, environment and ecology, depletion of traditional materials, etc [2].

Core MSE Courses

The undergraduate Mechanical Engineering program at our university includes two serial core courses Materials Science (MS), and Engineering Materials (EM). The MS course serves as an introduction to the science and engineering of materials (such as metals and alloys, polymers, and ceramics). Some of the main topics are crystal structure; imperfections (defects) in crystalline solids; mechanical properties; effect of deformation on material properties; and phase diagrams. The EM course focuses on major classes of engineering

materials, their properties and applications in design and manufacturing, and techniques of performance enhancement. Material types covered are metals and alloys, plastics and rubbers, ceramics, and composites. Emphasis is on manipulation of material properties, and use of the Ashby method for material selection. The MS course serves as a prerequisite for the EM course and the course on Manufacturing Processes. All the three materials and manufacturing courses form prerequisites for the Final Year Project that runs for the last two semesters and consists of designing, constructing, and testing of a complex mechanical product. During the last year, students can also opt for electives offered in this area, such as Advanced Materials Technology, Corrosion Engineering, etc. Course outcomes for the MS course from a recent semester are shown in Fig-1.

Materials Science: Course Outcomes

Letters in parentheses denote ABET-based program outcomes/performance indicators (a,b,e,j), and Bloom's taxonomy (cognitive) levels (L1,L2,L3,L4).

Upon the successful completion of this course, students should be able to:

1. Understand the basics of engineering materials and their role in the development of societies and industries [a2, a3]
2. Understand the relationship between structure and properties of materials [a2, a3; L1, L2, L3]
3. Understand relationship of mechanical properties of materials to strength, fracture, fatigue, and creep [a2, a3; L1, L2, L3]
4. Understand and distinguish between different types of imperfections present in metals and alloys, and the effect of deformation on mechanical properties of materials [a2, a3, e1, e2; ; L1, L2, L3]
5. Understand phase diagrams and phase transformations, and their effect on mechanical properties of metals and alloys [a2, a3, e1, e2; L1, L2, L3]
6. Understand the basics of non-metallic materials such as ceramics and polymers, and advanced materials [a2, a3, j; L1, L2, L3]
7. Conduct materials science experiments including microstructure/metallography, and strength related properties of materials, and analyze experimental results [b2, b3; L2, L3, L4]

Figure-1 Course outcomes from a recent course outline of Materials Science (MS)

Current Work

The most important task in engineering education (or any other discipline) is a clear-cut and meaningful description of course objectives and outcomes, followed by compatible and consistent instructional strategy and assessment scheme [3]. Over the past fifteen years at our university, setting up of objectives for MSE courses has moved progressively, incorporating ABET student outcomes, performance indicators, and Bloom's taxonomy [4], [5]. One of the recent approaches for the scientific design of course outcomes and delivery/assessment plans is the Dee Fink's model of significant learning and integrated course design [6]. The current paper is a work-in-progress, describing this approach. Though the strategy is being tried out in both the MSE courses (MS and EM), this paper takes examples and activities from the first core course (MS). This methodology of incorporating significant learning and integrated course design can be easily adapted to other engineering and science (and even arts and business) courses.

Fink's Significant Learning Approach

Education in today's world should be more focused on equipping an individual to be creative and innovative [7]. High quality learning also incorporates collaborative information sharing, exchange of learning experiences, and cooperative activities in virtual learning environments, which meet international standards [6], [7], [8]. A more important aspect of education quality is whether the students have received a significant and lasting learning experience.

Significant learning comes into reality when the focus is targeted on learner performance rather than teacher performance, and behavior rather than subject matter. It is also notable that the knowledge acquired in an active manner (instead of passive) helps students to learn and retain knowledge in a better way [8], [9]. In order to ensure significant learning experiences, the course must be designed and managed appropriately.

Designing courses for significant learning may follow various approaches, depending on the learning objectives [10]. The content-centered approach is the most common and traditional one, while the alternative learning-centered approach is more recent [8]. A more systematic approach of Integrated Course Design has been proposed by L Dee Fink [6]. Compared to past learning experiences, integrated course design takes more time, thought and energy. However, this pays off well in delivering a significant learning experience for the students.

The well-known Bloom's taxonomy of educational objectives [11] focuses only on cognitive learning. Building up on the Bloom's model, Fink [6] proposed a taxonomy of significant learning (Fig-2) consisting of six major types and their sub-categories, adding the elements of self-motivation and human interaction. A hierarchical structure is followed in Bloom's taxonomy, whereas Fink's taxonomy is circular, indicating multidirectional learning. It is claimed that using Fink's taxonomy, enhancement of a student's learning ability in any one area improves the abilities in the other areas, delivering a better significant learning experience [12]. For instance, an improvement in caring category will motivate to learn foundational knowledge, while integration skill will reflect in learning more about themselves (human dimension).

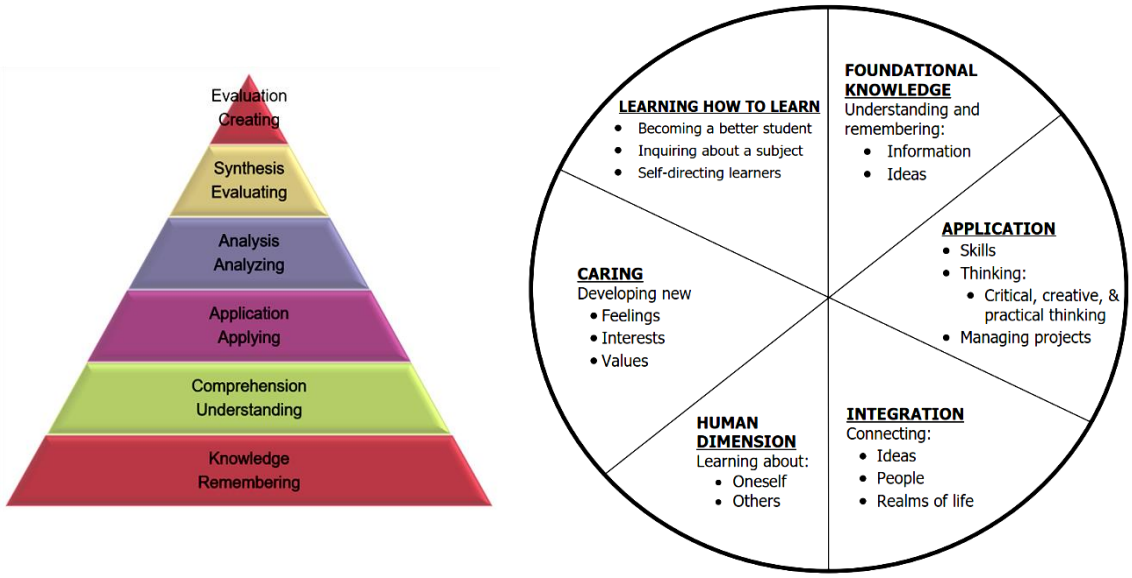

Figure-2 Bloom's taxonomy of cognitive goals (left), and Fink's taxonomy of significant learning (right)

Foundational knowledge in Fink's scheme covers the first two levels of Bloom's taxonomy: basic knowledge (information and ideas) and understanding of the subject. *Application* is the same in both schemes: applying basic knowledge to understand higher-level topics or to solve problems. However, in Fink's system, it also includes the upper-level skills of analysis and evaluation/creation, utilizing critical thinking as a tool. *Integration* is a new element: connecting the various aspects of the course (theoretical, experimental, applications, etc) into

a meaningful whole. The elements *human dimension* and *caring* relate more to the other taxonomy of Bloom's called 'affective goals' that targets values, attitudes, and interests. *Learning how to learn* targets independent learning, more in line with ABET outcomes of 'broad education' and 'life-long learning.'

Significant Learning of Materials Science

Achieving the targets of significant learning in the teaching of MSE courses is very important. Hoddinott and Young [13] examine what instructors and students think about teaching of generic skills in an MSE school. Employers from materials related companies emphasize that apart from discipline-specific academic/technical knowledge, recruits should possess other abilities such as effective communication, working in teams, critical thinking, independent problem-solving, and being self-starters. Guido [14] describes the use of an innovative modular approach for the teaching of materials science and engineering. Modular instruction contains a series of independent but inter-connected activities that include clear-cut instructions for learners, explanations, exercises, and generalizations. These activities target well-defined objectives such as analysis and application of concepts and techniques, active participation of students, and stimulation of individual interests.

As mentioned earlier, Fink's significant learning approach has been recently adopted for the teaching of MSE courses in the undergraduate mechanical engineering program at our university. Figure-3 is a depiction of Fink's 3-column course design applied to a basic Materials Science course (MS). The three columns describe learning outcomes, learning assessments, and learning activities. The rows represent the various levels and domains of Fink's taxonomy: foundational knowledge, application, integration, human dimension (self and others), caring, and learning how to learn.

As is obvious, all course elements described in catalog course description and course outline (Fig-2) are not covered in Fig-3. The idea here is to present the methodology through selected portions of the course, rather than showing every course element. For instance, foundational knowledge will also include other areas of the course such as stress-strain relationships and mechanical properties, phase diagrams, and properties and applications of materials (metal alloys, polymers, and ceramics). These other course contents (not explicitly shown in Fig-3) will also be covered (wherever appropriate) in the domains of application, integration, human dimension (self and others), caring, and learning how to learn. A few novel elements summarized in Fig-3 are explained below through appropriate examples.

The idea of *integration* is implicitly embedded in every course, but Fink's 3-column table forces us to address it explicitly. One learning outcome of this nature could be "identify major classes of engineering materials and discuss their role in the development of societies and industries." Learning activities would include lecture/explanation on the mini-project, and project presentations by student teams including question-answer sessions. Assessment could include individual and group mini-project / term paper, consisting of both written report and oral presentation.

Addressing the soft aspect of *human dimension* (both self and others) in a science/ engineering course like MS can be a daunting task. Learning outcomes could be "actively participate in class discussions; avoid plagiarism in report writing and properly cite published sources; work in teams on mini-project, swapping roles as team member and leader; and conduct peer assessment of project team members." Learning activities could be lecture and class discussion on team work, and professional and ethical responsibility (including

plagiarism, citation and referencing); and project presentations and discussions. Assessment methods could be keeping records of active class participation (individual and group); records of meetings with project teams for individual and team work; grading of reports for plagiarism and proper citation and referencing; and student peer assessments.

	Learning Outcomes	**Learning Assessments**	**Learning Activities**
Foundational Knowledge	• Describe major classes of engineering materials and their representative properties • Describe basic types of crystal structure and their relationship to material properties • Describe different types of imperfections present in metals and alloys, and the effect of deformation on material properties	• Quizzes and exams containing descriptive (or multiple-choice) questions	• Lectures and powerpoint presentations • Video presentations on material testing techniques
Application	• Solve numerical problems related to crystal structure, stress and strain, phase diagrams, etc • Conduct materials science experiments (strength-related properties of materials; cold work; heat treatment; microstructure and metallography) • Convert experimental data into graphs (wherever applicable), and analyze and interpret the results	• Quizzes and exams containing numerical problems • Lab reports on conducted experiments (group work)	• Lectures and powerpoint presentations • Interactive problem solving sessions and tutorials • Lectures on lab experiments, and lab work
Integration	• Identify major classes of engineering materials and discuss their role in the development of societies and industries	• Individual and group mini-project / term paper (written report and oral presentation)	• Lecture on mini project • Project presentation and Q/A session
Human Dimension - Self	• Actively participate in class discussions • Avoid plagiarism in report writing, and properly cite published sources	• Assessment record of active participation • Assessment of reports for plagiarism and proper citation and referencing	• Lecture and class discussion on professional and ethical responsibility (including plagiarism, citation and referencing)
Human Dimension - Others	• Work in teams on mini-project, swapping roles as team member and leader • Conduct peer assessment of project team members	• Records of meetings with project teams for individual and team work • Student peer assessment	• Lecture and class discussion on team work • Project presentations and discussions
Caring	• Discuss the effect of engineering materials on environment, ecology, and sustainable development • Ask critical questions during presentations, maintaining decorum and politeness	• Related questions in quizzes and exams • Assessment of term paper and project presentation	• Lecture and class discussion on individual and team mini projects • Project presentations and discussions
Learning How to Learn	• Handle independently portions of different chapters marked as self-study, and prepare for quizzes and exams • Use library, internet, and any other sources to study certain assigned topics, write concise reports, and prepare for quizzes and exams	• Related questions in quizzes and exams • Assessment of term paper and project presentation	• Lecture and class discussion on self-study tasks, individual and team mini projects • Project presentations and discussions

Figure-3 Fink's significant learning strategy for Materials Science (MS) course

This is the first instance of using Fink's taxonomy of significant learning and the associated integrated course design approach in the teaching of the MS course at our university. A survey was conducted at the end of the semester to collect student responses on the achievement of course outcomes using this methodology. Full survey results would become more meaningful after the course is offered a few more times using this approach. However, student responses during class activities and discussions, and the course survey indicate that the new approach (description of course outcomes, and planning and execution of learning activities and assessments) is well received. Students feel that they are learning the basics of MSE in a more well-structured, and lively, energetic, and interactive atmosphere.

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