AC 2008-2629: DESIGN AND INTEGRATION OF A CAPSTONE COURSE TO ACHIEVE PROGRAM OUTCOMES

Mohamed El-Sayed, Kettering University

Professor of Mechanical Engineering and director of the Hybrid Vehicles Integration Laboratory. He has been teaching at the undergraduate and graduate level for over 30 years. He teaches Machine Design, Automotive Design, Machine Design Capstone, Automotive Design Capstone, Design Optimization, Advanced Mechanics of Materials, linear and Nonlinear Finite Element analysis, and Design for manufacturability. He has been a PI and Co-PI on several research grants and a consultant to several engineering corporations. He has over seventy research papers in addition to several patents.

Steven Beyerlein, University of Idaho

Professor of Mechanical Engineering. He has been teaching Sophomore Design, Senior Design, and Combustion Engine Systems, testing of catalytic engine systems, conducting action research in the college classrooms, teaching and documenting open-ended problem solving, and designing professional development activities. He is a Member of the Transferable Integrated Design Engineering Education (TIDEE) consortium that produced and field tested a three component Design Team Readiness Assessment. He is a Co-PI on the NSF Enriched Learning Environment grant with primary responsibility for the formation and ongoing development of a community of research-based classroom practitioners at the University of Idaho

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Abstract

A capstone is the top and last stone in a building. Similarly, a capstone course is usually the peak and last experience for students in a higher education program. Depending on the discipline and institution capstone courses may take the form of group projects, senior seminars, research, or any other activity that successfully integrates and synthesizes what students have learned through the academic program. Originally a capstone course may have been viewed as a "finishing touch" to provide students with the needed information or skills before graduation, hence the name "capstone". Recently, the prevailing perspective is that a capstone course is an opportunity for students to "demonstrate" that they have met the goals established by their educational program. While the original view may lead to focusing on knowledge exchange and skills development with no measures relative to a reference profile, the recent view may cause no extra meaningful knowledge and skills to be developed in the course. It is the development of a common desired profile at the exit point of both the program and the capstone course that a meaningful experience for students to close the gap between the students' state at the course entry and the desired program outcomes can be achieved. This paper addresses the natural integration of a capstone course with its educational program from a logical perspective. This perspective goes beyond providing the "finishing touch" and mere "demonstration" to actively pursue the profile of an expert in the field as the logical outcome for the course and the program.

Introduction

Capstone courses and experiences are the "culminating experiences in which students synthesize subject-matter knowledge they have acquired, integrate cross-disciplinary knowledge, and connect theory and application in preparation for entry into a career.[1] Capstone courses are usually taken last in the sequence of courses at the end of the senior year. The First National Survey of Senior Seminars and Capstone Courses conducted in 1999 suggested that these courses place the highest priority on culminating learning in the academic major, and more than 70% require a major project or presentation.[2]

While the form of a capstone course varies from one discipline to another, the desired outcome of providing students with a meaningful experience before their exit from the academic program is the same. The views, philosophies, and means of achieving this desired outcome, however, may vary from one institution to another. In some cases, the pedagogical approaches and views vary from one faculty to another in the same academic department. The reason is that while the value and importance of capstone courses are universally realized, a common universal definition or view has not been agreed upon yet. The multitude of definitions, however, can be grouped in the following two main views for the capstone courses and experiences:

- Originally, a capstone course was viewed as a "finishing touch" to provide students with the needed information or skills before graduation, hence the name "capstone". With further development on this view a capstone course became, a culminating experience in

which students are expected to integrate special studies with the major, and extend, critique, and apply knowledge gained in their major[3] or to be a cumulative and integrating experience[4] and should be both a synthesis – reflection and integration – and a bridge – a real-world preparatory experiences, with emphasis on integration, experiential learning, and real-world problem solving.[1,5]

- In another developing view, a capstone course is "demonstration". To elaborate a capstone course is an opportunity for students to demonstrate that they have achieved the goals for learning established by their educational institution and major department.[6] Since, in addition to cognitive skills, learning can occur in two other domains (affective and psychomotor,) a capstone course allows for a mix of evaluative styles that assess the broad range of the students' past experiences.[7]

Through careful examination of both views it is clear that the learning outcomes will vastly depend on the interpretation and implementation of each view. While the original view may lead to focusing on knowledge exchange and skills development with no measures relative to a reference profile, the second view may cause no extra meaningful knowledge and skills be developed in the course. In the following a view of the capstone course or experience that allows the natural integration with the educational program outcome is discussed.

The role of a capstone course in any educational program

By definition and design capstone courses are the closest to the exit point of a higher education program. Therefore, it is natural for a capstone course in any discipline to share the same learning outcomes of the education program. It is also natural for the capstone course to be guided by the program's vision during the design, implementation and assessment of the course. In this paradigm, the main mission of a capstone course, in a specific discipline is: to close the gap between the program's goal state and the learners' state at the entry point to the course. By achieving the course learning outcomes, based on this vision and mission, the capstone course assessment can be viewed as the program assessment as well.

This view of a capstone course or experience depends on how the education process as whole is viewed. When an educational program is designed the learning outcomes can be viewed as the desired attributes or abilities of the learner at the end of the program. The program itself becomes the process through which these attributes are achieved. Each designed course in the program is a sub-process with its learning outcomes incrementally contributing to the final program learning outcomes in the field of study. Each course or sub-process is designed for the learner development towards the final goal state and validation based on the course set criteria or outcomes. While the development is continuous the validation can be distributed across the course duration or increments. However, final validation based on the set criteria, in the form of grade or pass/fail, is necessary for the learner to move to the next phase.

Capstone courses, by design, are usually the last phase for development and validation of the program itself. For this reason capstone courses, concerning the validation aspect, should share the final validation criteria with the program. As for the development aspect all the efforts during the course should be driven to close the gap between the learner state entering the course and goal state at the end of the course as well as the program. In the light of this view of the course, the previously discussed prevailing views can be explained as focus on development in the case

of the "final touch" view or focus on validation in the "demonstration" view. It is important, however, to realize that development without consideration of the goal state and validation of its achievement can be ineffective. Also, validation without guided development assumes that the goal state have been reached before entering the capstone course which limits the value added to the learner.

Integrating a capstone course with an engineering educational program

The key to integrate a capstone course with the program is: the course should share the same vision and outcomes with the program. In addition to a program's specific outcomes there are five common types of learning outcomes in higher education: competencies, movement, accomplishments, experiences, and integrated performance. These can be mapped to different dimensions of social learning as described by Wenger.[8] Each type is best suited to distinct educational methods and requires collecting different evidence to demonstrate that the outcome has been achieved. A competency is a collection of knowledge, skills, and attitudes needed to perform a specific task effectively and efficiently at a defined level of performance. Movement is documented growth in a skill that can be transferred across disciplines. Accomplishments are significant work products or performances that transcend normal class requirements and are externally affirmed by an outside expert. Experiences are interactions, emotions, responsibilities, and shared memories that clarify one's position in relation to oneself, a community, or discipline. Integrated performance is the synthesis and application of prior knowledge skills, processes, and attitudes with new learning to address a difficult challenge within a strict time frame. For engineering education the scope and performance level of the previously discussed five outcomes can be guided by the use of an expert profile. In a particular discipline, an expert profile portrays the vision of active competencies, movement, accomplishments, experiences, and integrated performance in the field. [9]

The Transferable Integrated Design Engineering Education (TIDEE) engineering profile work produced a set of ten holistic roles of an engineer.[9] Descriptions of these holistic roles are given in Table 1. In addition, five observable behaviors supporting each role are given in Table 2. Each statement, in Table 2, begins with an action verb and includes detail that aids in visualizing the behavior. These statements are intended to be high-level manifestations of each behavior, extending beyond normal baccalaureate degree preparation. The behaviors given in Table 2 encompass all aspects of ABET engineering criteria with less overlap and clearer performance expectations. Because the profile is written to represent diverse engineering environments, not all stated behaviors are evident or necessary in a single job description.[9]

Table 1: Roles and Holistic Behaviors of an Engineer

Technical Roles	**Holistic Technical Behaviors**
Analyst	When conducting engineering analysis, the engineer adeptly applies principles and tools of mathematics and science to develop understanding, explore possibilities and produce credible conclusions.
Problem Solver	When facing an engineering problem, the engineer produces solutions that properly address critical issues and assumptions and that are conceptually and contextually valid.
Designer	When facing an engineering design challenge, the engineer develops designs that satisfy stakeholder needs while complying with important implementation, societal, and other constraints.
Researcher	When conducting applied research, the engineer designs and conducts studies that yield defensible results and answer important applicable research questions.
Interpersonal Roles	**Holistic Interpersonal Behaviors**
Communicator	When exchanging information with others, the engineer prepares, delivers, and receives messages that achieve desired outcomes.
Collaborator	When working with others in joint efforts, the engineer supports a diverse, capable team and contributes toward achievement of its collective and individual goals.
Leader	When providing needed leadership, the engineer promotes shared vision to individuals, teams, and organizations and empowers them to achieve their individual and collective goals.
Professional Roles	**Holistic Professional Behaviors**
Self-Grower	Motivated for lifelong success, the engineer plans, self-assesses, and achieves necessary personal growth in knowledge, skills, and attitudes.
Achiever	When given an assignment, the engineer demonstrates initiative, focus, and flexibility to deliver quality results in a timely manner.
Practitioner	Driven by personal and professional values, the engineer demonstrates integrity and responsibility in engineering practice and contributes engineering perspectives in addressing societal issues.

Table 2: Behavior-Based Profile of an Engineer

Role	Behaviors or Observable Actions
Analyst	a. Searches strategically to identify all conditions, phenomena, and assumptions influencing the situation b. Identifies applicable governing principles of mathematics, natural sciences, and engineering sciences c. Selects analysis tools consistent with governing principles, desired results, assumptions, and efficiency d. Produces and validates results through skillful use of contemporary engineering tools and models e. Extracts desired understanding and conclusions consistent with objectives and limitations of the analysis
Problem Solver	a. Examines problem setting to understand critical issues, assumptions, limitations, and solution requirements b. Considers all relevant perspectives, solution models, and alternative solution paths c. Selects models for obtaining solutions consistent with problem type, assumptions, and solution quality d. Uses selected models, methods, and data to produce desired solution e. Validates results, interprets and extends the solution for wider application
Designer	a. Searches widely to determine stakeholder needs, existing solutions, and constraints on solutions b. Formulates clear design goals, solution specifications (including cost, performance, manufacturability, sustainability, social impact), and constraints that must be satisfied to yield a valuable design solution c. Thinks independently, cooperatively, and creatively to identify relevant existing ideas and generate original solution ideas d. Synthesizes, evaluates, selects, and defends alternatives that result in products (components, systems, processes, or plans) that satisfy established design criteria and constraints to meet stakeholder needs e. Reviews and refines design processes for improved efficiency and product (solution) quality
Researcher	a. Formulates research questions that identify relevant hypotheses or other new knowledge sought b. Plans experiments or other data gathering strategies to address questions posed and to control error c. Conducts experiments or other procedures carefully to obtain reliable data for answering questions d. Uses accepted data analysis procedures to infer trends, parameters, and data error e. Interprets and validates results to offer answers to posed questions and to make useful application

Communicator	a. Listens, observes, and questions to assess audience background and information needs b. Documents and mines available information and differing perspectives for understanding and application c. Prepares a message with the content, organization, format, and quality fitting the audience and purpose d. Delivers a message with timeliness, credibility, and engagement that achieve desired outcomes efficiently e. Assesses the communication process and responds in real-time to advance its effectiveness
Collaborator	a. Respects individuals with diverse backgrounds, perspectives, and skills important to the effort b. Values roles, accepts role assignments, and supports others in their roles c. Contributes to development of consensus goals and procedures for effective cooperation d. Resolves conflicts toward enhanced buy-in, creativity, trust, and enjoyment by all e. Contributes to and accepts feedback and change that support continuous improvement
Leader	a. Facilitates and articulates a shared vision valued by targeted individuals, groups, or organizations b. Motivates others to action by crafting a compelling case for achieving individual and organizational goals c. Provides authority and resources and removes barriers to aid others' success d. Supports risk-taking and growth by creating trust, providing counsel, and modeling desired attributes e. Encourages achievement by recognizing and rewarding individual and group successes
Self-Grower	a. Takes ownership for one's own personal and professional status and growth b. Defines personal professional goals that support lifelong productivity and satisfaction c. Regularly self-assesses personal growth and challenges to achieving personal goals d Achieves development planned to reach personal goals e. Seeks out mentors to support and challenge future growth and development
Achiever	a. Accepts responsibility and takes ownership in assignments b. Maintains focus to complete tasks on time amidst multiple demands c. Takes appropriate actions and risks to overcome obstacles and achieve objectives d. Monitors and adapts to changing conditions to ensure success e. Seeks help when the challenge exceeds current capability in the given time constraints

Practitioner	a. Displays integrity, consistency, ethical, and professional demeanor in engineering practice and relationships b. Embraces and employs appropriate professional codes, standards, and regulations c. Engages with engineering professionals and organizations to support excellence in engineering practice d. Demonstrates citizenship through service to society on local, national and/or global scales e. Brings responsible engineering perspectives to global and societal issues

Creating an engineering capstone course

Creating a program or a course starts with a vision. In this vision, the program or the course is visualized as the process to achieve a set of learning outcomes that construct a visualized set of learners' long term behaviors. For a capstone course and an educational program the set of learning outcomes and the visualized set of learners' long term behaviors are the same. For an engineering capstone course and educational program the expert profile, defined in Table1 and detailed in Table 2, illustrates the visualized set of learners' long term behaviors. Once this shared vision and common learning outcomes, between the capstone course and the program, are established the steps for creating the capstone course can follow the Analysis, Design, Development, Improvement, and Evaluation (ADDIE) model.[10] In the following the specific considerations in applying the ADDIE model and steps to the creation of an engineering capstone course are discussed.

Course analysis

***Identification of long term behaviors*:** As stated before, the vision for the course as a development and validation process should be aligned with the defined long term behaviors desired in the learner by the program. These long term behaviors are guided by the vision of the expert profile in the professional practice of the discipline. The capstone course should be anchored, in behaviors typical of professionals in the field, by using key roles that are aligned with course intentions. Furthermore, identifying a small set of general actions associated with each role in the profile can serve as an effective prompt for developing profession-focused learning outcomes.

Identification of learner profile: Since the main role of a capstone course is to minimize the gap between the program's expert profile and the students' state it is critical after selecting the long term behaviors desired in a course, to analyze student preparation in prior coursework, decomposing targeted behaviors into subordinate skills and planning needed interventions to systematically cultivate these skills.[11] Hierarchies of cognitive domain, social domain, and affective domain learning skills are needed in doing this subordinate skill analysis. Any number of learning style inventories can be used to understand differences in student populations within a particular class.[12]

***Identification of gap*:** To define the gap it is very important to understand the learners' entry state to the course based on the learner profile of the previous step. This step can be guided by

the five observable behaviors supporting each role in the expert profile given in Table 2. These observable behaviors can be considered as the different dimensions of a multi-dimensional gap.

Identification of course intentions and outcomes: Beside any other intentions specific to the course and the program, the main intention of a capstone course is to minimize the gap between the learners' level and the goal state based on the long term behavior defined by the educational program guided by the expert profile .

Identification of learning outcomes priorities: Since the learning outcomes are shared with the program, the focus in this phase should be on establishing priorities for closing the relevant aspects or dimensions of the multi-dimensional gap. These efforts should be guided on the developed vision for the course and program, using the following methodology:

1. Prioritize professional roles emphasized by course type.
2. Select most relevant type(s) of learning outcome for each role.
3. Define role-driven learning outcomes using behavioral prompts from the profile.

The first step in crafting learning outcomes involves identifying roles emphasized in a particular experience. These depend on course type and context. The second step is identifying the type of outcome most closely aligned with each role in the professional profile. The third step involves projecting role behaviors given in the professional profile back into a specific course context. Writing outcome statements begins by noting which role behaviors given in the behavior based profile are relevant to the course context. Next, it is useful to formulate common questions about student performance associated with each of the key roles underlying a course. These questions are intended to remind the writer of important course intentions related to specified roles. Finally, learning outcomes should be written in response to the course intentions and questions about student performance, keeping in mind the type of learning outcome emphasized for each role.[9]

Course design and development

To achieve the desired outcomes, the type of a capstone course should be based on the course architecture and types of activities that best simulate those of an expert in the field, aligned with the learning outcomes, and aimed at closing the gap. Since the majority of the capstone courses in engineering are project-based, and these projects are in the form of design, it important to realize that the biggest differences, in activities, stem from the types of projects undertaken rather than the disciplines involved.[13] To achieve the five common types of learning outcomes in higher education the course project types and activities should be designed and developed towards:

- Elevating Competencies
- Facilitating Movement
- Empowering Accomplishments
- Expanding Experiences
- Integrating Performance

Course improvement and evaluation

The course implementation and improvement should be guided by the program shared vision to accomplish the mission of closing the gap based on the established priorities. When developing and implementing the continuous improvement through assessment and evaluation it important to identify the subject and the purpose. The main subjects are the learners, the capstone course and the program. The purpose is to continuously develop and validate for closing the gap between the learners entry state and the goal state of both the capstone course and the educational program. For continuous improvement of any of the subjects there are tools for developmental and tools for validation. When dealing with development assessment tools should be used and when dealing with validation evaluation tools should be used. For both assessment and evaluation the appropriate performance measures and standards should be established.

Assessment: There are five attributes for quality assessment which apply to any educational setting. These include: clearly communicated purposes, clear and appropriate targets, target and method matching, appropriate sampling, and elimination of bias and distortion. It is essential that all participants and users of an assessment understand why it is being conducted and how the results will be used.[14-17]

Evaluation: Learner success in a capstone course should be evaluated by measures that examine performance based on the observable prioritized behaviors supporting the roles in the expert profile given in Table 2. An example of the evaluation data for a design capstone course, implementing the methodologies developed in this paper at the mechanical engineering department of Kettering University, is shown in Figure 1. The mean evaluation scores of the design teams at the start and end of the course are presented. The evaluations are based on measures that examine performance for the top three prioritized behaviors, one from each role in the expert profile, established for the course.

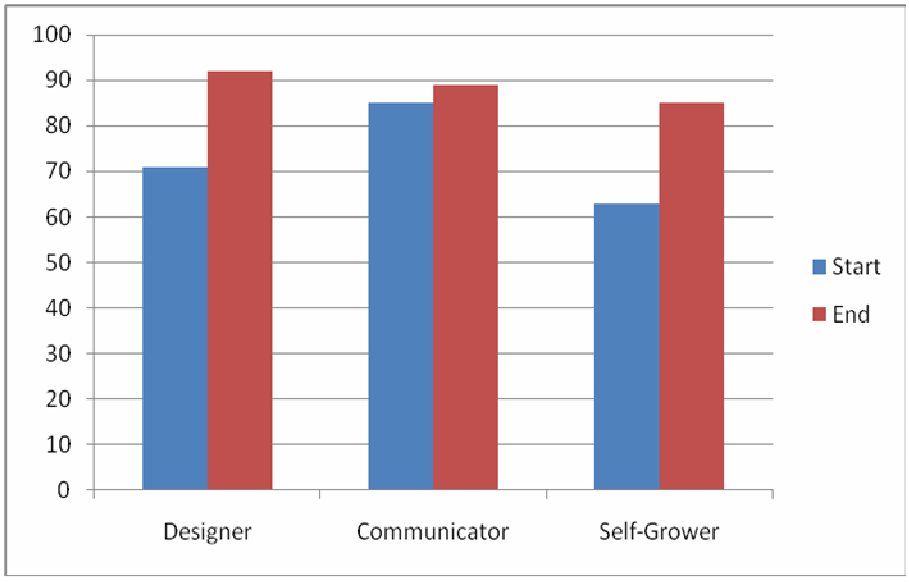

Figure 1: Mean evaluation score for top three behaviors of a capstone design course

Conclusion

An educational program can be viewed as a process of development and validation through which a set of desired learners' attributes can be achieved. Each course in the program is a sub-process contributing to the final program learning outcomes or goal state. Capstone courses are usually the last development and validation phase in the program. For this reason a capstone courses is both the final development and the final validation course in the program. Therefore, in regard to the validation aspect, a capstone course should share the final validation criteria with the program. As for the development aspect, all activities during the course should be driven to close the gap between the learner state entering the course and the desired goal state at the end of both the course and the program.

By sharing the learning outcomes and the expert profile a capstone course can be integrated with the program. Through successful integration, development, and implementation a capstone course can play an active role in achieving the program educational outcomes. With the shared vision and learning outcomes a capstone course can also provide a meaningful assessment and evaluation for the program continuous development and validation. With reliable assessment and evaluation frameworks for the, learner, the course, and the program a capstone can be a valuable tool for quality control and continuous improvement.

Due to rapid changes in professional practices in terms of knowledge, processes, required skills, and tools the environment of an expert in most disciplines is highly dynamic. In some discipline a learner entering into an educational program may face a totally different professional environment at the exit. While changes in programs may not be fast enough to adjust for the change in the professional environment, continuous adaptation at the capstone level could compensate for the deviations.

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