A Guideline for the Development of a Scenario-Based Senior Capstone Course for Construction Engineering and Management Students

Prof. Namhun Lee, Central Connecticut State University

Dr. Namhun Lee is a professor of Construction Management at Central Connecticut State University. His current research focuses on utilizing emerging technologies for improving construction efficiency and collaborations. Dr. Lee is also interested in enhancing construction education and training through innovative educational technologies.

Dr. Seong Jin Kim, Minnesota State University, Mankato

Seong Jin Kim is a Ph. D. in Building Construction. He had diverse teaching experiences in K-16 settings. His primary interests in research are class environments in teaching and performance improvements based on the team work and team alignment in cons

Dr. Jiyong Choi, Central Connecticut State University

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Abstract

A senior capstone course often stands as a defining feature of most undergraduate construction engineering and management (CEM) programs. Traditionally, this capstone course is designed to prepare students for the practical challenges of the construction industry. However, in today's dynamic landscape, the incorporation of new technologies, sustainability considerations, and evolving managerial demands has increased the complexity of construction projects, both technically and managerially. Consequently, the current construction industry places a premium on the critical thinking and problem-solving abilities of recent graduates. Regrettably, as observed in various professional fields, CEM programs have faced challenges in producing graduates equipped with the necessary problem-solving and critical thinking skills. To address this issue, the authors propose the development of a novel senior capstone course using a scenario-based learning approach. The authors' program is still in the process of creating this capstone course, following the ADDIE (Analyze, Design, Develop, Implement, Evaluate) instructional design framework. This culminating course is intended to provide senior students with the opportunity to integrate and apply the knowledge they have accumulated throughout their college years by simulating real-world situations. While the course is still under development, this paper primarily focuses on delineating the systematic approach of creating a senior capstone course tailored to CEM students and shares insights gained during this development process. Furthermore, the paper introduces the new scenario-based senior capstone course devised by the authors. The scenario-based senior capstone course promises a dynamic classroom experience, enabling students to apply the comprehensive array of skills they have acquired throughout the CEM curriculum to simulate pre-construction and construction processes. Finally, the paper offers recommendations for developing a senior capstone course using the scenario-based learning approach.

Introduction

In today's rapidly evolving construction industry, where advancements in technology and sustainability considerations are reshaping project landscapes, the demand for graduates equipped with critical thinking and problem-solving abilities has never been greater [1]. Construction Engineering and Management (CEM) programs play a crucial role in preparing students to meet these demands by providing them with practical knowledge and skills essential for success in the field. A cornerstone of most undergraduate CEM programs is the senior capstone course, traditionally designed to bridge the gap between academic learning and real-world application [19]. However, as observed across various professional fields, CEM programs have encountered challenges in producing graduates with the necessary problem-solving and critical thinking skills required by the modern construction industry [12]. In response to this issue, there is a growing need to rethink and innovate the structure and content of senior capstone courses to better align with the evolving needs of the industry. To address this need, the authors' program has proposed the development of a novel senior capstone course using a scenario-based

learning approach tailored to CEM students. This approach aims to provide students with the opportunity to integrate and apply the knowledge they have accumulated throughout their college years by simulating real-world situations commonly encountered in the construction industry.

The authors have taken a systematic approach for the development of the scenario-based senior capstone course, following the Analyze, Design, Develop, Implement, and Evaluate (ADDIE) instructional design framework [4]. The main objective of this paper is to share insights gained during the course development process. In addition, the paper shares recommendations and best practices for creating an engaging and effective senior capstone course that prepares students for the challenges of the current construction industry. The authors believe that, through a comprehensive exploration of the scenario-based learning approach and its application in the context of senior capstone courses, this paper contributes to the ongoing dialogue on innovative approaches to construction education and highlights the importance of adapting curriculum to meet the evolving needs of the industry.

Scenario-Based Learning

Scenario-based learning, an instructional approach that utilizes real-world situations, engages learners and promotes a deeper understanding of concepts [17]. By immersing learners in realistic scenarios, it encourages active participation, problem-solving, and critical thinking. This pedagogical approach has gained popularity in recent years due to its effectiveness in fostering meaningful learning experiences. It involves presenting learners with realistic scenarios or case studies that simulate authentic situations they may encounter in their field of study or professional practice [14]. These scenarios challenge learners to apply their knowledge and skills to solve problems, make decisions, and achieve learning objectives in a contextually relevant manner [6].

Research studies have demonstrated the effectiveness of scenario-based learning across a wide range of disciplines and educational levels. For example, a study by Ashcroft *et al.* found that medical students who engaged in scenario-based learning outperformed their peers who received traditional instruction in terms of diagnostic accuracy and clinical reasoning skills [2]. Similarly, in the field of business education, Burrell *et al*. found that scenario-based learning improved students' decision-making abilities and prepared them for real-world challenges in the business environment [5].

Successful implementation of scenario-based learning requires careful planning and consideration of several key elements, which include authenticity of scenarios, clear learning objectives, interactive design, and feedback mechanisms [15]. They are crucial for creating effective scenario-based learning experiences that engage learners and promote meaningful learning outcomes.

In conclusion, scenario-based learning is a valuable instructional approach that promotes active learning and deepens understanding through real-world contexts. By immersing students in authentic scenarios, scenario-based learning prepares them for success in their academic and professional endeavors.

The ADDIE Instructional Design Framework

The ADDIE (Analyze, Design, Develop, Implement, Evaluate) instructional design framework is a systematic approach widely used by instructional designers to create effective and efficient learning experiences [3]. It provides a structured model for analyzing learning needs, designing instructional strategies, developing learning materials, implementing instruction, and evaluating the effectiveness of the learning experience. The ADDIE framework consists of five phases as shown in Figure 1 [13].

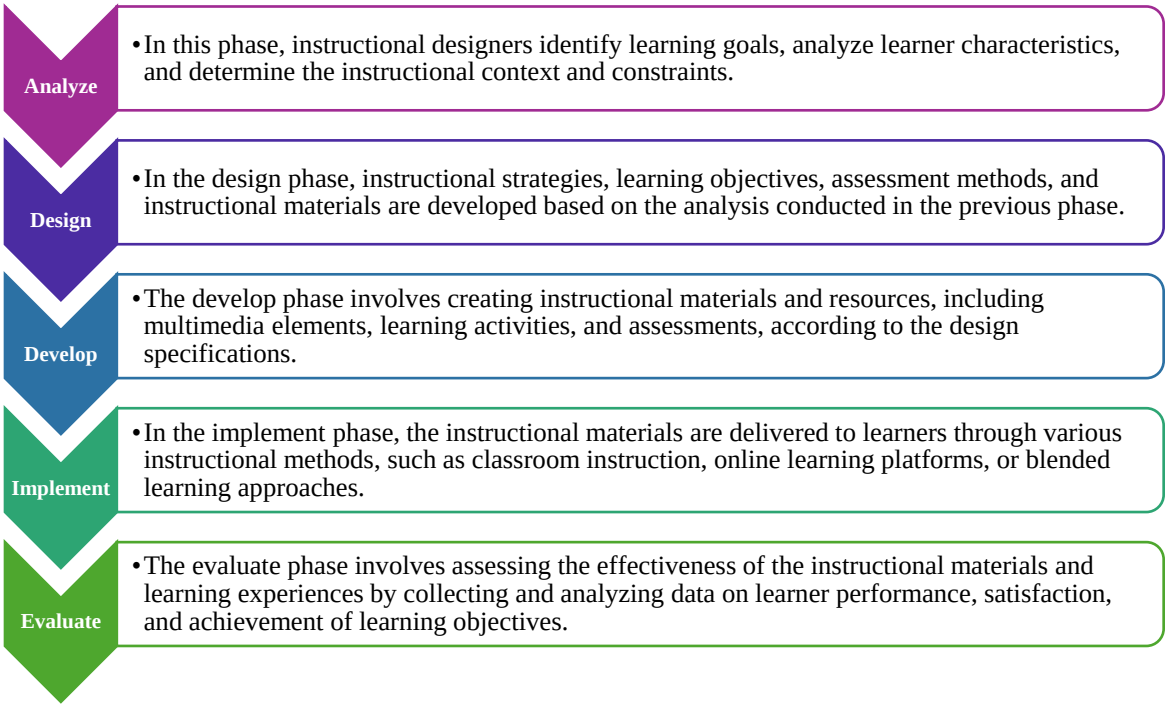

Figure 1. Overview of the ADDIE Framework

The ADDIE framework can be applied to various educational contexts, including K-12 education, higher education, corporate training, and professional development [18]. It is used to design a wide range of instructional materials, such as curriculum units, online courses, training modules, and educational games. The ADDIE framework offers several benefits for instructional designers and educators, including [16]:

- Systematic approach: Provides a structured process for designing and developing instructional materials.
- Flexibility: Can be adapted to different instructional contexts and learning needs.
- Collaboration: Facilitates collaboration among instructional designers, subject matter experts, and other stakeholders.
- Continuous improvement: Allows for ongoing evaluation and revision of instructional materials to improve effectiveness.

The ADDIE instructional design framework is a valuable tool for designing high-quality instructional materials and enhancing learning experiences. By following a systematic approach,

instructional designers can create effective and efficient learning solutions that meet the needs of diverse learners [3].

Senior Capstone Course in Construction Engineering and Management Curriculum

The senior capstone course serves as a culminating experience for students enrolled in Construction Engineering and Management (CEM) programs. It is designed to allow students to synthesize their learning, demonstrate mastery of core concepts, and apply their skills in real-world scenarios [13]. The senior capstone course typically spans one semester and is structured to include a combination of classroom instruction, project-based learning, and hands-on experiences. The course aims to achieve the objectives as shown in Figure 2 [10].

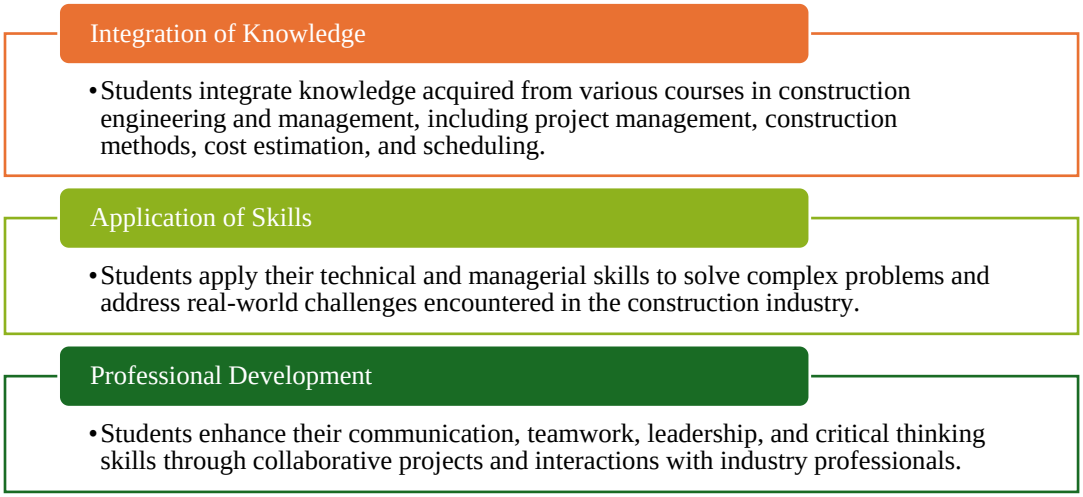

Figure 2. Main Capstone Course Objectives

The senior capstone course plays a crucial role in preparing students for careers in the construction industry by providing them with hands-on experience, industry-relevant skills, and networking opportunities [11]. It allows students to gain practical experience working on real construction projects, develop a deeper understanding of industry practices, and build relationships with potential employers.

Best practices for implementing a successful senior capstone course include [13]:

1. Industry Partnerships: Collaborate with industry partners to provide real-world projects, guest lectures, and internship opportunities for students.
2. Project-Based Learning: Emphasize project-based learning to simulate real construction projects and engage students in hands-on learning experiences.
3. Mentorship and Guidance: Provide mentorship and guidance to students through faculty advisors, industry mentors, and career services to support their professional development.

The senior capstone course is a critical component of the CEM curriculum, providing students with valuable learning experiences and preparing them for successful careers in the construction

industry [7]. By integrating classroom learning with hands-on experiences and industry partnerships, the senior capstone course enhances student learning and professional preparation.

Development of the Scenario-Based Senior Capstone Course

The development of the scenario-based senior capstone course has followed the ADDIE instructional design framework, which involves the following phases: Analyze, Design, Develop, Implement, and Evaluate as aforementioned. In the Analyze phase, the authors thoroughly reviewed several capstone courses offered in other CEM programs and worked with industry advisory boards. Consequently, the needs of CEM students and the requirements of the construction industry were assessed to determine the course objectives and learning outcomes. The key findings of this phase are summarized in Table 1.

Table 1. Scenario-Based Capstone Course Information

Course Description	This course integrates various facets of the construction engineering and management process by applying knowledge and techniques obtained through the construction engineering and management program to effectively oversee a construction project. Focus is placed on fostering team collaboration, proficient project management, informed decision-making, and adept problem-solving skills using up-to-date construction documentation.
Course Objectives	Prior to entering the workforce, students are required to showcase their capability in developing and overseeing a pre-construction building project. This involves utilizing management tools and process control systems aligned with real contract documents and construction projects. Moreover, students must integrate and apply the knowledge and skills acquired throughout their enrollment in the construction engineering and management program, including any prior construction work experience, to meet course objectives and effectively execute project development.
Course Learning Outcomes (CLOs)	1. Apply synthesized knowledge and concepts from previous coursework to a commercial construction project. 2. Comprehend and apply principles related to sustainable construction. 3. Utilize various computer software programs such as RS Means Data Online, Procore, Bluebeam, Primavera P6, Microsoft Project, AutoCAD, SketchUp, and Revit to effectively manage the construction process. 4. Demonstrate coherent and professional oral and written communication skills.

In the Design phase, the course structure, content, and assessment methods were outlined based on the identified objectives and outcomes. The Develop phase has involved the creation of course materials, including scenarios, case studies, and instructional resources. The Implement phase focuses on the delivery of the course to students, while the Evaluate phase assesses the effectiveness of the course in achieving its objectives and meeting the needs of students and the construction industry.

Table 2 outlines the proposed scenario-based capstone course. In this course, students will participate in simulated activities centered around a commercial construction project. They will assume various responsibilities, including planning, estimating, scheduling, contracting, and administering the project's development. Students or teams will be challenged to showcase their learning outcomes through the course assignments (Refer to Table 2) that highlight their abilities.

The colored elements outlined in Table 2 are independent components crucial for developing the final project deliverables. Students will demonstrate their understanding of each component

throughout the course through written reports and oral presentations, both of which will be used for assessment purposes. To culminate their learning, students will deliver a final project report and a professional presentation to faculty, a panel of judges, and guests at the end of the capstone course. It is imperative for the course instructor to provide guidance and encouragement to students, ensuring they adhere to established milestones to prevent their projects from falling behind. Additionally, students may need to adapt to the evolving requirements of the project and its stakeholders throughout the course.

Table 2. Outline of the Proposed Scenario-Based Capstone Course

Assignments	Software Requirements	CLOs
Develop an organization chart for the team or construction company, outlining personnel responsibilities.		**#1 & #4**
Create pre-qualification documents following the AIA 305 form.		
Understand construction pricing methods, bidding strategies, and project delivery systems.		**#1 & #4**
Evaluate all associated contract risks using the appropriate AIA contract document for the capstone project.		
Develop a site logistics plan, including a drawing.	AutoCAD, SketchUp, or Revit	**#1, #3, &#4**
Develop a safety plan that includes site-specific job hazard analysis. Establish a project-specific quality management system based on ISO 9001:2015 requirements.		**#1, #3, &#4**
Summarize a document control plan including Requests for Information (RFIs), submittal logs, inspection logs, daily reports, etc.		
Demonstrate the team's process control approaches for submittal review, change orders, weekly meeting minutes, etc.	Procore	
Create a risk management plan.		**#1 &#4**
Summarize team's project approach.		
Identify key project milestones and create a master schedule. Produce an overall project cost estimate.	Primavera P6 or Microsoft Project, RS Means Data Online, Bluebeam	**#1, #3, &#4**
Develop a staffing plan and select trade partners for the project.		**#1 &#4**
Develop a project accounting document using the AIA schedule of values (referencing the AIA G702 document).		
Analyze cash flow broken down by month using a line of credit.		
Develop a plan that outlines eco-friendly practices and proposes value engineering suggestions for cost-effective implementation.	AutoCAD, SketchUp, or Revit	**#1, #2, #3, &#4**

To ensure effective communication and documentation, students will utilize Procore for central document storage, questions, clarifications, and capturing weekly meeting minutes of project/team activities. Bluebeam will be used for markups and collaborative review throughout the project deliverables development process.

Implementation Plan for the Scenario-Based Senior Capstone Course

The senior capstone course is envisioned to be a cornerstone of our undergraduate CEM program, providing students with a platform to synthesize and apply their accumulated

knowledge and skills in simulated real-world scenarios. A crucial aspect of this course is the way scenarios are presented. By anchoring them in real-world contexts, the authors aim to motivate student learning and enhance active engagement. This is achieved by presenting individual assignments (detailed in Table 2) that feature diverse scenarios. These scenarios will challenge students to utilize critical thinking skills as they identify, analyze, and respond to real-world construction challenges. To illustrate this approach, a recent example scenario used in this course is presented (see below):

Scenario for Developing a Sustainable Construction Plan

A solar energy system offers property owners a practical solution for reducing energy costs. Modern solar panels and photovoltaic (PV) systems are user-friendly to install, require minimal maintenance, and operate efficiently over the long term, leading to significant energy savings. In response to this, the owner has requested an analysis of the cost and timeline implications associated with installing a solar system sized to offset 50% of the facility's electricity consumption.

To determine the cost of the necessary solar system, we will need to consider the size and efficiency of the solar panels along with any spatial limitations on the roof. The analysis summary must provide details on:

- *Specifications of the solar panels*
- *The designated roof area for installation*
- *Cost implications*
- *Projected timeline for installation*
- *Underlying assumptions used in the analysis*

This comprehensive evaluation will equip the owner with valuable insights into the feasibility and benefits of implementing a solar solution for the facility.

A crucial factor is the average electricity usage of the building. According to the U.S. Energy Information Administration (EIA), nursing homes and senior care centers use around 17.4 kilowatt-hours (kWh) of electricity per square foot annually. This provides a reliable foundation for our analysis. To achieve a more accurate estimate, contacting the facility to obtain their historical electricity consumption data would be ideal. For other variables like sun hours per day, solar panel orientation, and efficiency, reasonable assumptions should be made and clearly outlined in the report.

The success of this course hinges on the collaborative efforts of three key stakeholders: instructors, students, and construction professionals from the industry advisory board (IAB). Each plays a distinct role and has specific responsibilities, working together to support a successful learning experience for all.

<u>Students:</u>

- Teamwork: Students work in teams of 4-6 throughout the semester. Once formed, team composition remains unchanged to foster collaboration.

- Rotating Roles: Students rotate through various project roles like project manager, engineer, superintendent, estimator, and scheduler, gaining experience in diverse aspects of construction management.
- Project Initiation: The capstone project begins with a mandatory kick-off meeting where the IAB judges, representing construction professionals, present the Request for Proposal (RFP) problem along with all relevant documents and guidance.
- Project Execution: Students utilize Procore for issuing Request for Information (RFIs) and promptly post weekly meeting minutes documenting team activities.
- Deliverables and Presentations: Students develop plans, assemble deliverables, and make oral presentations based on their findings. Each team member must present for a minimum of two minutes, effectively addressing judges' questions.

Instructors:

- Scenarios Development: Instructors play a critical role in crafting the foundation for student learning by developing engaging and relevant scenarios. These scenarios serve as the cornerstone of the capstone course, immersing students in realistic construction challenges that mirror real-world project complexities.
- Learning Facilitation: Instructors guide the learning process while students execute the capstone project. This involves responding to student RFIs related to the RFP problem and coordinating all course activities between student teams and the IAB judging company.
- Instruction and Feedback: Instructors oversee specific assignment topics, providing students with brief lectures as needed, addressing their questions and concerns, and offering feedback on their work.
- Attendance and Evaluation: Instructors attend the semester-opening RFP kick-off meeting and judge all bidding team presentations to evaluate their performance on bid day.

IAB Judging Company:

- RFP Development: The IAB plays a crucial role by sponsoring the RFP. Each IAB meeting selects a judging company. This company collaborates with the course coordinator to prepare the RFP problem statement and then develops and presents the RFP through a kick-off meeting at the semester's start.
- Guidance and Support: The judging company serves as a point of contact for instructors regarding the RFP problem throughout the semester. They provide clear direction to student teams and assist them by offering briefings, responding to faculty-forwarded RFIs, and scoring final deliverables and presentations.
- Debriefing and Awards: The judging company concludes the course by providing a debrief about the actual project, offering insights into real-world successes and challenges.

Recommendations for Developing a Senior Capstone Course

Similar to other capstone courses in engineering disciplines, the capstone course is designed to provide students with a final opportunity to synthesize and contextualize their learning within the

context of curriculum. Figure 3 illustrates the key elements in developing a CEM senior capstone course.

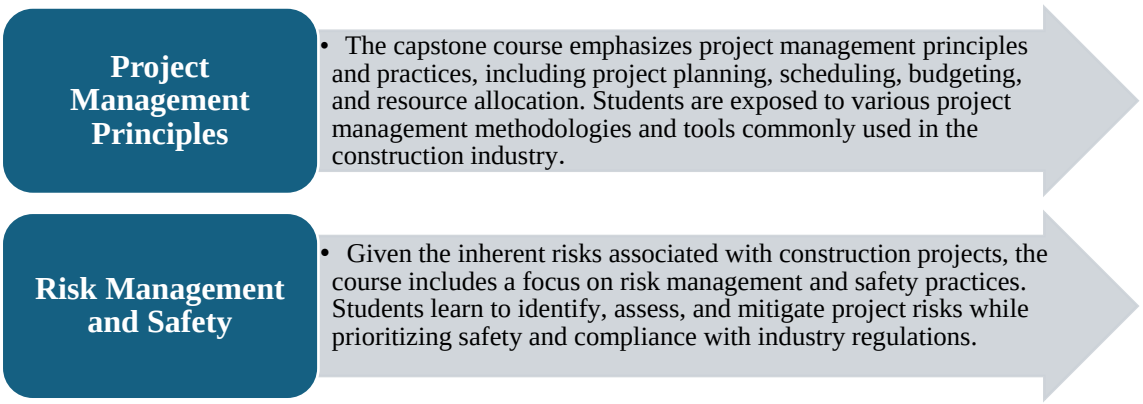

Figure 3. Key Elements of CEM Senior Capstone Development

Through this course development process, several key characteristics that define the success of CEM capstone course have been identified, including:

- **Integration of Multidisciplinary Concepts:** The course is structured to address a wide range of concepts and practices, including project planning, scheduling, budgeting, risk management, sustainability, and stakeholder coordination. This interdisciplinary approach reflects the multifaceted nature of construction projects in the real world.

- **Focus on Practical Application:** Students are tasked with applying their acquired knowledge and skills to address complex challenges within the construction industry. Capstone projects simulate real-world construction scenarios, providing students with hands-on experience in project management and decision-making.

- **Integration of Emerging Technologies:** The construction industry is continually evolving with the introduction of new technologies and methodologies [9]. The course incorporates the latest advancements in construction management software, building information modeling (BIM), and other emerging technologies to prepare students for the challenges of the current construction landscape.

- **Client and Stakeholder Communication:** Effective communication with clients, stakeholders, and project teams is paramount in construction project management [8]. The course emphasizes the development of communication skills necessary for successful project delivery, including negotiation, conflict resolution, and client management.

- **Emphasis on Professionalism and Ethical Behavior:** The course emphasizes the importance of professionalism and ethical behavior within the construction industry. Students are expected to adhere to industry standards and codes of conduct while navigating various project challenges.

- **Collaborative Learning Environment:** The capstone course fosters a collaborative learning environment, with students working in teams to tackle real-world construction projects. This collaborative approach mirrors the dynamics of professional construction projects, emphasizing teamwork, communication, and leadership skills.

Discussions

Through a combination of coursework, hands-on projects, and industry engagement, the scenario-based capstone course provides students with a comprehensive educational experience tailored to prepare them for successful careers in construction project management. By integrating theoretical knowledge with practical application and emphasizing professionalism, ethics, and collaboration, the course equips students with the skills necessary to excel in the dynamic construction field.

The scenario-based capstone course offers a dynamic classroom experience where students apply a comprehensive array of skills acquired throughout the CEM curriculum to real-world construction projects. Following a systematic approach to course development and incorporating scenario-based learning principles, CEM programs better prepare graduates for the challenges of the current construction industry.

Designed specifically for senior CEM students, this course offers them the unique opportunity to apply their acquired knowledge and skills to real-world construction situations. Through collaborative team projects, students compete for construction contracts, engaging in simulations of pre-construction and construction processes. Emphasizing critical thinking, problem-solving, teamwork, communication, and project management, the course effectively prepares students for success in the contemporary construction industry.

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