Redesign of Purdue Construction Engineering and Management (CEM) Capstone Course

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INTRODUCTION

In large part, the evaluation of construction engineering education has gone untouched since its inception post-WWII (Abudayyeh et al., 2000). More specifically, the curriculum and overall content for the construction engineering education within the Purdue Construction Engineering and Management (CEM) curriculum has remained fundamentally unchanged since its development in the late 1970s. There is a call to reform construction engineering education for students' future development before they enter the construction profession (Bernold, 2005). CEM will be positioned as a leader in the reform because of the resources accessible to the CEM program:

- Academia - Purdue is home to the first School of Engineering Education (Purdue University, 2022).
- Learners - students who must complete 36 weeks of experiential learning as part of the degree requirement.
- Profession - industry relationships established with an active Industry Advisory Board (IAB) and industry partners participating in the experiential learning process.

CEM is addressing the call for reform through several initiatives. The reform will initially focus on the CEM Capstone course redesign, which will be the benchmarking tool for future reform. The framework of this research utilizes three of the initiatives (1) the 2007 stakeholder analysis, (2) the April 2016 CEM Industry Advisory Board meeting, and (3) the Spring 2018 IMPACT program.

In May of 2007, CEM students developed the stakeholder analysis study of construction engineering and management (CEM) at Purdue University. The CEM seniors noted in their analysis that the curriculum of CEM is outdated and needs an overhaul. The analysis discusses the desire of the students to see "more dynamic/comprehensive course requirements that include all required skills necessary for the industry." The seniors specifically said that the CEM Capstone course (CEM 425) could be improved and that they need to be "more applicable to current industry practices." Technology is an important tool in the construction industry, especially in scheduling and estimating. While it is essential to get the background and understand how to do things by hand, instruction should include new and current methods because they will provide "better learning opportunities." Structuring the instruction based on the stakeholder analysis's insight would allow the students to prepare for the workforce.

In April of 2016, the CEM Industry Advisory Board (IAB) convened, and part of the agenda for the proceeding involved discussion regarding Engineering Education (ENE) recommended practices, specifically CAP and curricular priorities. The discussion provided a significant amount of information that informed CEM of what the profession was looking for relative to knowledge the CEM students should have upon graduation.

In the spring of 2018, the author enrolled in the IMPACT program to redesign the CEM Capstone course. The IMPACT program provided access to scholarly mentors, a community of practice, and a sequential guide to course redesign. These tools allowed the IMPACT Fellows (instructors and faculty) to unpack their course of choice for the redesign and test aspects within their community of practice alongside their cohort's assigned mentors.

Several limitations existed before the fall of 2019 for the CEM Capstone course. The CEM Capstone course was only offered in the fall semester and the contents covered in the class did not emulate the current trends of the industry. The course did not cover two phases: (1) pre-construction (e.g., business development and feasibility analysis) and (2) post-construction (e.g., facility operation and maintenance). Furthermore, the curricula of the CEM Capstone (CEM 425) did not reflect the skill sets and knowledge that the current industry professionals think the students should gain upon graduation to apply to current industry practices (Bernold, 2005; Hegazy et al., 2013; Schexnayder & Anderson, 2011). Hence, there was a ***need*** to review and transform the CEM 425 course to better reflect the students' and industry professionals' demands. This research ***aimed*** to propose and demonstrate a new CEM Capstone course(s) curriculum that can deliver topical content to incubate industry-ready professionals. To achieve the objective, this study (1) conducted a literature review about curricula priority and assessment, (2) mapped learning outcomes of CEM lower-level courses, and (3) designed a preliminary structure of the new two-semester long capstone courses. The anticipated contributions of this study are:

- Academia – expand the intersection of Engineering Education (ENE) and Construction Engineering Education (CEE) field.
- CEM courses – execute the deployment of ENE and CEE recommended practices in a CEM course as part of a continuous improvement process to meet the need of the learner and the profession.
- Students – execute the continuous improvement process on the CEM Capstone course to provide academic experiences that are student-centered and authentic.

LITERATURE REVIEW

The literature review provides detail of the ENE recommended practices that the author used in the CEM Capstone course redesign. Each recommended practice blended to ground and inform the author so the course redesign would align with the call for reform.

<u>Accreditation for Construction Education</u>: Felder & Brent (2003) identified that engineering educational programs are required for accreditation to meet ABET Criteria relative to curriculum and instruction. Their paper outlined the challenge in doing this but was guided by subscribing to three principles: (1) planning, (2) instruction, and (3) assessment. Planning is merely defining the content and what objectives will be measured. Instruction is simply the pedagogy for which knowledge will be conveyed and

transferred to the student from the instructor, a variety of methods can be applied depending upon the content transfer. Still, ultimately instructors should strive for a deep and authentic learning opportunity. Assessment is an instrument of measurement which comes in many forms, either individually or as a group. Their work is very similar to the Content, Assessment, and Pedagogy (CAP) framework that is used to guide the course redesign (Streveler, 2014). Felder & Brent also stated that if instructors prepare in this manner with awareness and application of the ABET criteria, the challenge is obtainable.

Curricular Priority: Wiggins & McTighe (1998) was one of the more influential literature in this research. The introduction of the curricular priorities concept has catapulted this research into course curriculum design and overall construction engineering curriculum redesign. The curricular priorities concept links the backwards design concept previously discussed by providing a support tool and method for structure development. Curricular priorities are defined by the following categories: (1) Enduring understanding, (2) Important to know and do, and (3) Worth being familiar with. Their research expanded upon the illustration of the curricular priorities and links those with assessment tools, an essential bridge for instructors to guide learners' knowledge development.

Student-centered Pedagogy: Chi (2009) documented and explored the philosophy of constructivism (discovery learning), an overt learning activity. The instructor provides the learner with an environment in which the students are inquisitive such that the learner constructs "the rules and relationships." Discovery learning deploys a variety of methods to pursue learning objectives. Methods include but are not limited to concept mapping, taking notes, self-explaining, comparing and contrasting cases, generating predictions, and reflection.

Case-based and collaborative learning: The philosophy of community of practice can be intertwined with the collaborative learning discussion provided. Before this research, a generic description was applied to the approach to learning by the researcher that was more likely a characterization-based nomenclature rather than a sophisticated articulation; the author should concede that collaborative learning is: "a situation in which two or more people learn to attempt to learning something together." This is an important distinction because, too many times in team-based (collaborative learning), one member will work in a silo on a topic while yet other members do the same on other topics individually. Dillenbourg (1999) assisted in defining approaches, techniques, and language to describe collaborative learning, which brings guided structure to the concept-network development. Fulk et al. (2019) implemented case-based and collaborative learning to CEM sophomores and high school seniors.

Project-based learning (PBL): Hmelo-Silver (2004) discussed the definition of the PBL approach; the "teacher acts to facilitate the learning process rather than to provide knowledge." The goals of PBL are intended to assist students in developing: (1) Flexible knowledge, (2) Effective problem-solving skills, (3) SDL (self-directed learning), (4) Effective collaboration skills, and (5) Intrinsic motivation. In addition, Hmelo-Silver "discusses the nature of learning in PBL and examines the empirical evidence supporting it." Hmelo-Silver indicated there is a significant gap in the research on PBL because it has mainly been conducted on high-achieving students in gifted programs and/or medical programs; therefore, Hmelo-Silver claimed there is little knowledge on how this impacts learners with less aptitude than those generally found in the gifted education programs as well as those in medical education. "The evidence suggests that PBL is an instructional approach that offers the potential to help students develop flexible understanding and lifelong learning skills" (Hmelo-Silver, 2004).

This current state of published engineering education (ENE) and construction engineering and management (CEM) realized that there was an intersection of these fields that would allow one to inform and the other to be grounded. This exercise would bring more awareness to the intersection; the contributions of this study would be (1) academic – other CEM-related departments throughout the country to evaluate their curriculum, (2) learner – CEM students are expected to have experience-centered and authentic learning environments, and (3) professional - would employ prepared individuals and allow them to support the continuous improvement of academia and learner experience.

PROPOSED PURDUE CEM CAPSTONE

Determination of the Project Life Cycle and Topics of the Capstone Course

From the literature reviews and reviews of peer institutions' CEM Capstone curriculum, the study sees many benefits for students if the capstone course replicates the construction life cycle over two semesters (approximately 32 weeks of academic calendar at Purdue). To replicate concepts of construction project life cycle in CEM Capstone courses, this study classifies a construction life cycle into six phases which are (1) administrative business development and feasibility phase, (2) conceptual design phase, (3) design development phase, (4) final design and pre-construction phase, (5) project execution (or construction) phase, and (6) operation and maintenance phase. The first three phases are covered during the fall semester (first semester), and the other three are addressed during the spring semester (second semester). The four weeks of the first semester will be dedicated to the topics and discussions relating to the administrative development feasibility phase. Both the conceptual design phase and the design development phase have six weeks of the timeline. During the second semester, the final design phase, construction phase, and O&M phase will have four weeks, ten weeks, and two weeks of the academic calendar, respectively. The schedule can be modified according to the enrollment of the CEM capstone course and the selected project types.

This study considered the students' two potential career roles (i.e., a contractor and a consultant) to decide what topics and contents needed to be discussed during the two semesters. The career paths are becoming contractors who will perform primarily on job sites and consultants (or owner representatives) who will support construction projects remotely. The proposed CEM Capstone delivers these topics and contents at appropriate times throughout the two semesters. This study identified six essential topics to be covered during the capstone courses – this can be defined as key learning outcomes (KLO): (1) communication-related topics, (2) engineering economics-related topics, (3) engineering ethics-related topics, (4) legal aspects, (5) safety aspects, (6) design-related topics. The following subsection describes how this study determined and prioritized KLO.

Figure 1 shows the proposed CEM template replicating six construction project life cycle phases embedded into the two-semester concept for the CEM Capstone course. CEM Capstone instructors can utilize this template to develop detailed capstone course plans.

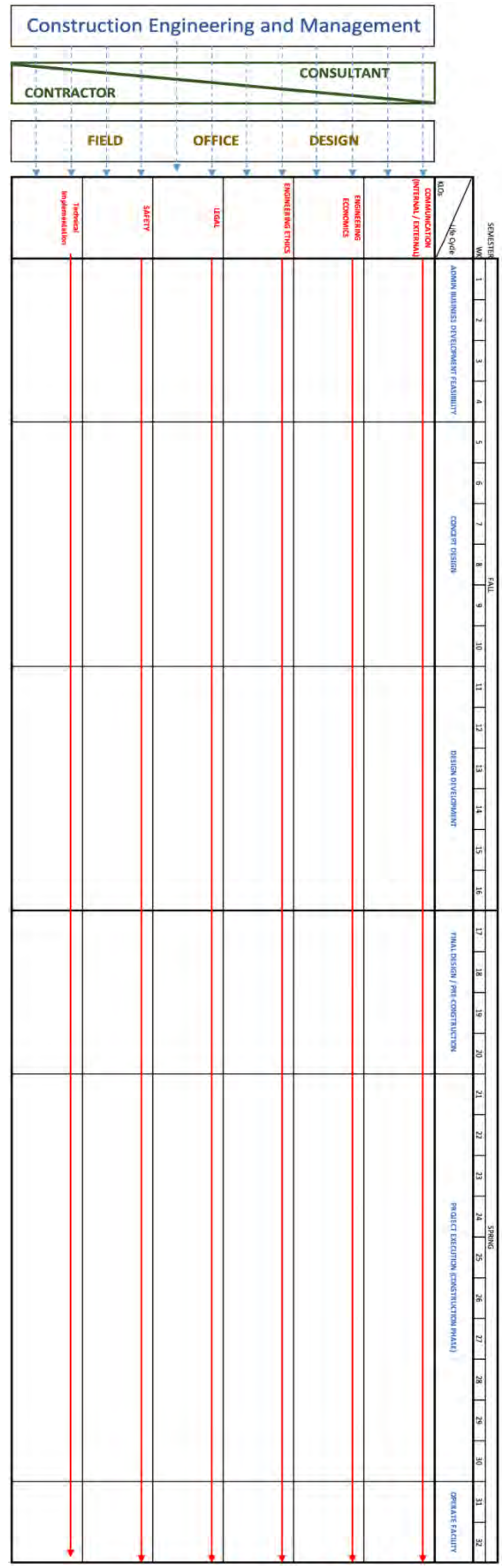

Figure 1 The Proposed CEM Template that Replicated Six Construction Project Life Cycle Phases Fitted into Two Academic Semesters (Equivalent to 32 Weeks)

<u>Determination and prioritization of learning outcomes</u>

The instruction developed with this capstone transformation will key in on the motivated undergraduate student entering their specific professional field upon completing the Bachelor of Science in Construction Engineering. The students can and will enter entry-level positions with various titles. However, as reflected in CEM senior exit surveys, most will join on a tract that will steer them into a management or field operations career. How does entry-level construction engineering professional distinguish themselves from their peers? CEM structure aids in this effort with the engineering curriculum. With this study, the author will build upon the construction engineering curriculum and develop an example for future improvements aimed at developing elite builders. The vision is that the elite builders (or master builders) will be prepared in the classroom. The elite builder will encompass the skill sets that embody the management and field operations tract throughout the construction project life cycle.

The CEM Capstone course redesign takes the first step in preparing learners for the profession. The CEM Industry Advisory Board and the faculty worked to prioritize curricula for the construction engineering program at Purdue, which guided the course redesign during the April 2016 biannual meeting. The IAB consists of more than 20 industry representatives that hold positions as owners, executives, or project managers. The IAB members are all Purdue graduates and nearly all CEM graduates. The IAB worked in groups, utilized discussion sessions, and documented their output on "white sheets." The output from the educational exercise developed a list that quantified and formulated the curricular priorities. The list (Figure

2 and 3) provides a tabulation of the results, which summarizes the proposed instructional outcomes and goals, detailed in this section's remaining portions.

- The enduring understanding is the development of work plans to complete day-to-day operations for a project that will be integrated into a comprehensive schedule to complete a project safely and economically. In developing the master builder, the ability to cultivate the knowledge base is found to be a work plan that is tangible and deliverable. Some components are similar regardless of the type of construction: schedule, material, labor, and equipment but depending upon the type of construction, the analysis and selections will differ. The enduring understanding of this study is intended to be the catalyst for the development of the new-aged master builder.
- What is Important to Know and Do focuses on the assessable components (or sub-area) of the enduring understanding, which should allow the instructor to deduce that the learner is accumulating skills. The skills will be developed via sessions and enriched in modules to promote mastery of the enduring understanding using the community of practice theory as the foundation of learning with ideas and learning practices implemented. The session and module concept will be discussed further in this project.
- Various knowledge and topics fall into the "worth being familiar with" category relative to construction engineering. Knowledge worth being familiar with will be used to analyze work and develop work plans. In most cases, the knowledge will consist of material that the student will be responsible for learning outside the classroom in preparation for application in the classroom.

Enduring Understanding

- FE/EIT Passed
- Professional, Ready to go
- Safety Conscious & Assertive
- Leadership Skills – Craft Relatable
- Continually improvement focused
- Problem solver
- Adaptable
- Self-Starter
- Good communicator
- OSHA Certification
- Project Planning
- Budgeting/Cost control
- Scheduling
- Teamwork
- Time management
- Comprehensive problem analysis
- Passion for Construction Industry
- Integrity
- Personality
- Desire to Build
- Strong Technical Understanding (pass FE)
- Company & Peer feedback
- Always open to learn/curious
- Basic Technology/excel/PM software
- Budget/Project Controls
- Service to Customer
- Critical Thinking
- People Skills

Important to Know

- Computer Skills
- Schedule
- Formwork
- BIM/VDC/Autocad
- Unions/Labor Relations
- Workforce training
- Equipment usage
- Estimating
- Soft skills (teamwork & communication
- Spec/Plan Reading
- BIM/Facility Management
- Conflict Resolution
- Stress Management
- Bidding
- Scheduling
- Cost Accounting
- Problem Solving
- Temp Design
- Safety
- Document Control
- Leadership/TEAM
- P6
- Industry Software
- Modeling
- Team Dynamic
- Construction Vocabulary
- Excel Spreadsheet
- Productivity
- Basic Terminology
- Excel
- Communication Skills
- Industry software basics
- Communication – oral, written, safety
- Cost Control
- MEP Awareness
- Codes/Standards
- Workforce Training
- Sub-contractor situations
- What's next in industry?
- Engineering class
- Legal/Contracts
- Budgeting
- Finance
- Bracing Design
- Cash Flow
- Concrete Construction
- Construction Claims
- Design Process
- Dewatering
- Earthwork
- Equipment costs & Accounting
- Sitework
- GIS
- Masonry Construction
- Leadership
- Materials performance under loads
- Operational Costs
- Project Controls
- Quality Concepts
- Resource Management
- Sheeting Design
- Shoring Design
- Steel structures
- Unions

Figure 2 Identified Topics of Curricular Priorities ("Enduring Understanding" and "Important to Know") for the Proposed Capstone Course by IAB Members in 2016

Worth Being Familiar With

- Hydraulics
- HR
- Bonds/Liens/RM
- Facilities Management
- Electrical
- Insurance
- Business Plans
- Technical Writing
- Design Process
- Labor Relations
- BIM
- Contract Types
- Project Life Cycle
- Project Planning
- Safety
- Quality Processes
- Lean Processes
- Risk Management
- Temp Str.
- Marketing
- Estimating
- Legal Aspects
- Design (firms, scaffolds, etc)
- Project Structure (IPD/Design-Build)
- Negotiations
- Finance
- Accounting
- Bidding
- Thermo Equipment
- Arbitration Litigation
- Labor Negotiations/Union
- Specific Trades
- Design Details
- Labor agreements
- Basic Eng Classes
- Site planning/Logistics
- Contractors obligations
- Cost Reports
- Productivity Analysis
- Claims
- Misc. Design Related Topics
- Insurance Issues
- Earthwork
- Concrete
- HVAC
- Piping
- Masonry
- Codes
- Business Writing
- Computer Graphics (Technology)
- Bonds
- Bridge Construction
- Business Plans
- Capital Project Analysis
- Career Development
- Cofferdams
- Data Analysis & Metrics
- Database
- Facility Management
- Infrastructure Data Mngmt
- Information Modeling
- Intellectual Property
- Mediadtion
- Monte Carlo Simulation
- Worker Motivation
- Network Diagrams
- Numerical Methods
- Organization Types
- Professional Liability
- Proposal Development
- Schematic Design
- Strategic Planning
- Timer Construction
- Torts
- Underpinning
- Wind Loads

Figure 3 Identified Topics of Curricular Priorities ("Worth Being Familiar With") for the Proposed Capstone Course by IAB Members in 2016

Mapping of identified topics and prioritized learning outcomes in CEM

This study investigated where the identified topics are being covered in the low-level courses in CEM at Purdue. The investigation includes the seven CEM courses the students would take before the capstone course. These courses are CEM 201 – Life Cycle Engineering and Management of Constructed Facilities; CEM 280 – Construction Engineering Professional Development I; CEM 301 – Project Control and Life Cycle Execution of Constructed Facilities; CEM 324 – Human Resource Management in Construction, CEM 380; Construction Engineering Professional Development II; CEM 455 – Temporary Structures in Construction; and CEM 485 – Legal Aspects of Construction Engineering (the students can take CEM 324, 455, and 485 concurrently). Depending on the course setting, the students will have different opportunities (e.g., traditional lectures, labs, homework, term projects, and/or presentations) to learn these topics in the courses. Hence, this study had individual meetings with the instructors of these courses to survey when and how the identified topics of curricular priorities are discussed in each course.

For instance, during the 16 weeks of the course CEM 201, the students will learn various topics to the instructor's structure and schedule. After an interview with the instructor of the CEM 201, this study identified that the topic of "budgeting and cost control," which is one of the "enduring understanding" topics, is being covered in the lecture materials in week 8 (lecture topic: construction scheduling and life cycle cost analysis), week 9 (lecture topic: project cash flow and project funding) and week 11 (lecture topic:

equipment ownership). Similarly, the topic of "equipment usage" of "enduring understanding" is being taught in the lecture materials in week 11 (equipment ownership), week 12 (equipment productivity I), and week 13 (equipment productivity II). The overall course mapping for the topics is shown in Figure 4.

At the end of this mapping process, this study counted how many times each topic had been covered throughout the degree program. For example, the topic of "project measurement" has been discussed 14 times (six lectures, six homework, and two projects) in the seven courses. This study, finally, was able to identify what topics are never discussed in CEM courses. The topics that were never discussed are: (1) service to customer, (2) GIS, (3) next in industry, (4) quality concepts, (5) insurance, (6) intellectual property, (7) marketing, (8) schematic design, (9) torts, and these are shown in the second page of Figure 5.

CONCLUSION

This study proposed a new CEM Capstone course. This course was developed based on industry feedback and inputs of curricular priorities, leading to increased student satisfaction and buy-in on the work. This course provides authentic projects with stakeholders mimicking real-world situations (32 weeks of project life cycle) for the students. Some of the challenges that the instructor observes during the first implementation are (1) the success of the project is dependent upon stakeholder engagement and available information, (2) the instructor will encounter more challenges if there are various project types and more available projects for the students, (3) the instructor should cooperate with multiple stakeholders to develop projects and to secure space in which the student can work in for the execution phase, and (4) the students had to deal with team members' graduation and transition between two semesters. These challenges will impact the overall students' performance and the success of the projects.

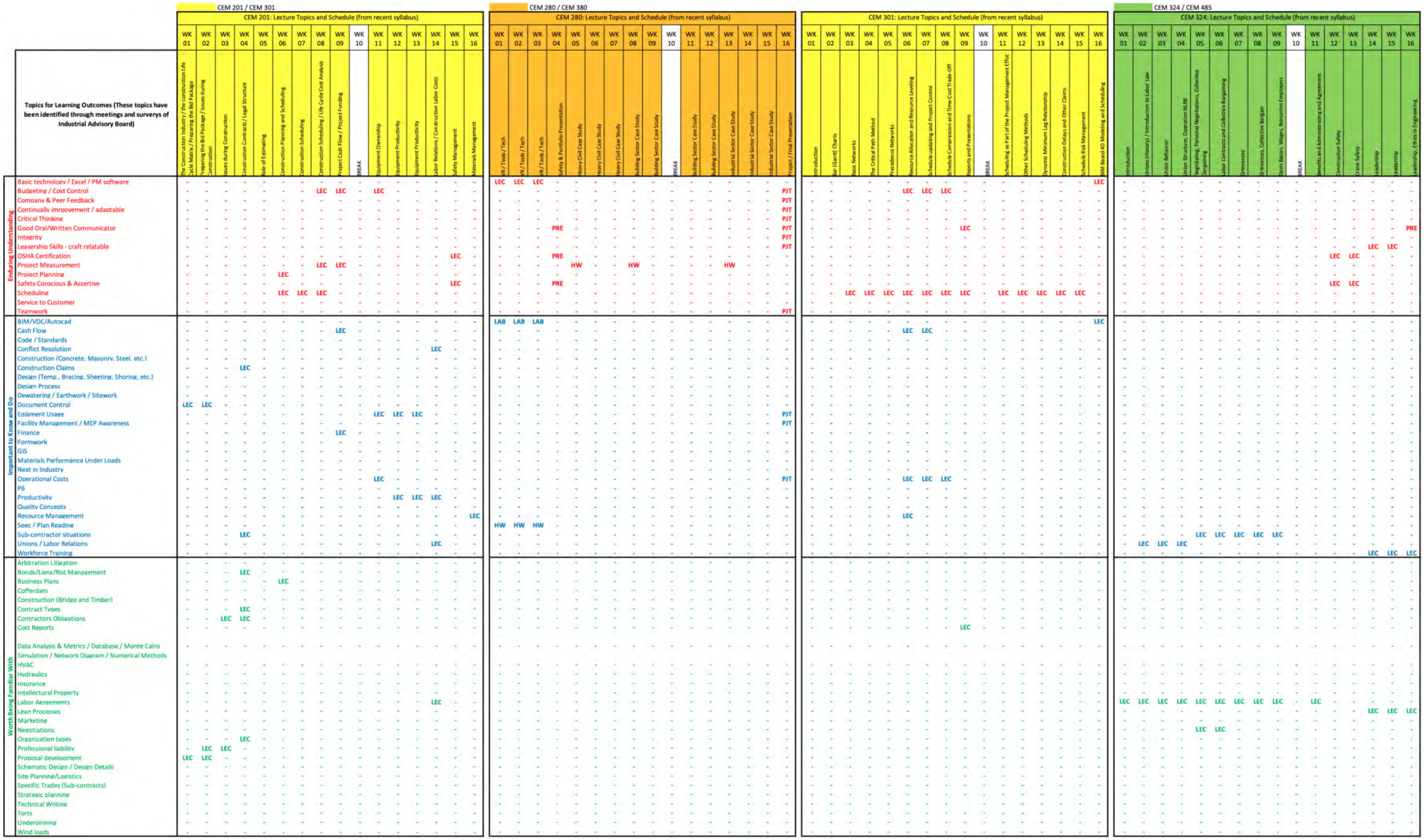

Figure 4 Mapping the Identified Topics of Curricular Priorities in Lower Level CEM Course

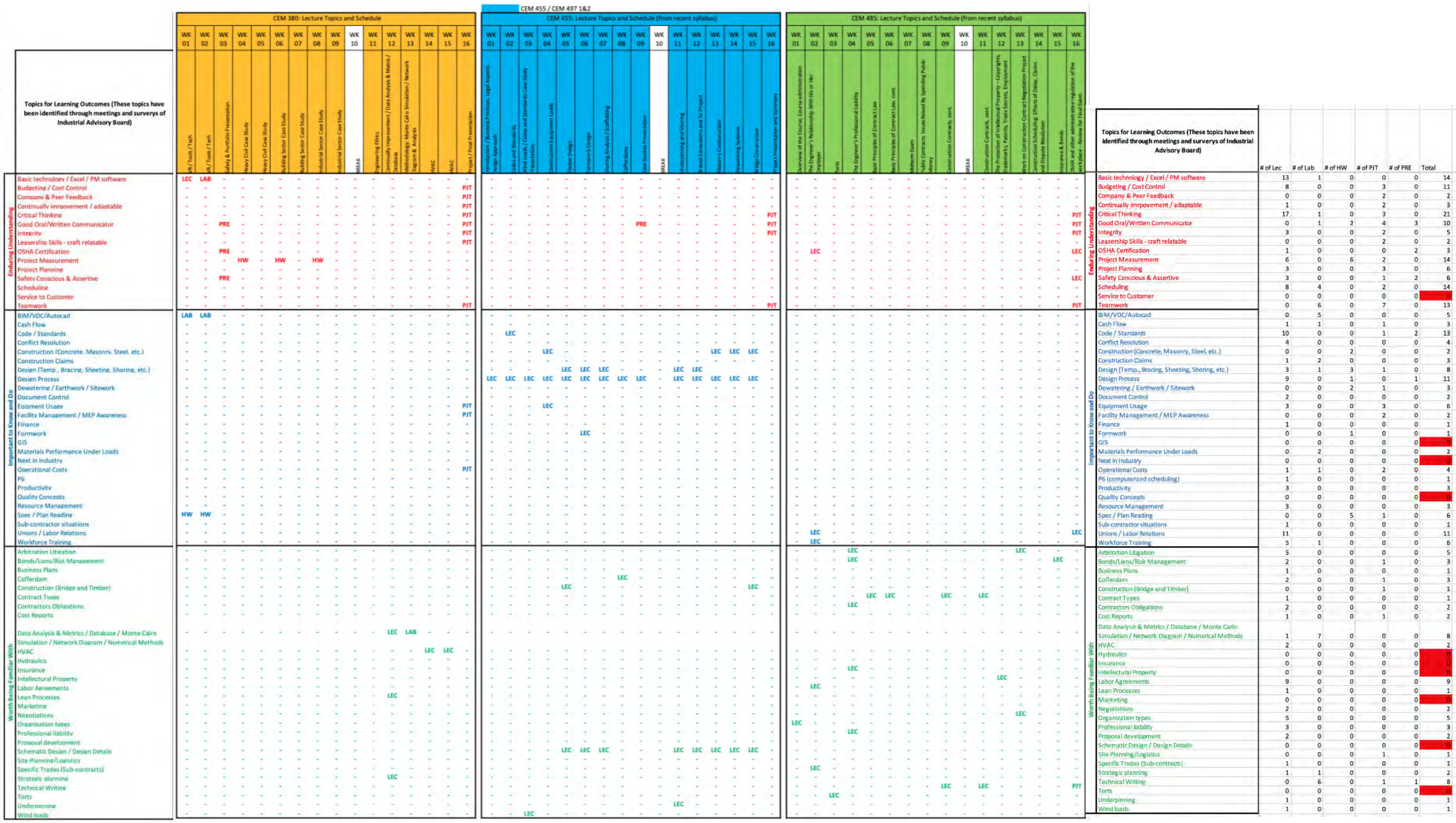

Figure 5 Mapping the Identified Topics of Curricular Priorities in Lower Level CEM Course (continued)

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