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Investigating Construction Courses within the US Civil Engineering Curricula – A Resource for Designing the Course

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Abstract

Construction courses in the civil engineering curriculum significantly contribute to the technical and professional knowledge, even if students do not follow a career in construction. Construction courses are offered during the junior or senior year of studies and meet several of the learning outcomes of the Accreditation Board for Engineering and Technology (ABET) Criterion 3. Additionally, the engineering topics covered are necessary for the successful completion of both the National Council of Examiners for Engineering (NCEES), Fundamentals of Engineering (FE) and Principles and Practice of Engineering (PE) exams. The study undertakes an online search and examines the construction courses offered by the civil engineering programs at major US universities. Information is imparted about the prerequisite courses, the credit hours, and the topics taught. The paper examines how well the topics taught align with the student outcomes of the ABET Criterion 3, the American Society of Civil Engineers (ASCE) Body of Knowledge (CEBOK 3), and the FE and PE civil engineering exams. The paper recommends specific topics and strategies for improving the course content, or for creating new construction courses. The research concludes that undergraduate construction courses contribute significantly to the technical and professional knowledge of future civil engineers and need to be included in the curriculum.

Introduction

This study undertakes an online search and examines the construction courses offered by the civil engineering programs at major US universities. Information is imparted about the prerequisite courses, the credit hours, and the topics taught. The paper examines how well the topics taught align with the student outcomes of the ABET Criterion 3, the American Society of Civil Engineers (ASCE) Body of Knowledge (CEBOK 3), and the Fundamentals of Engineering (FE) and Principles and Practice of Engineering (PE) civil engineering exams. We make recommendations about the topics to be included in new or existing construction courses.

According to the US Bureau of Labor and Statistics the construction industry employs the highest percentage of civil engineers next to the architectural, engineering, and related services category [1]. Construction education is important for the future civil engineers and is needed for upgrading the skills and knowledge of the construction personnel [2]. Although different majors can benefit from a construction engineering course according to a survey administered at an undergraduate civil engineering program (see Figure 1), this study addresses only the civil engineering curricula and undergraduate courses that the US civil engineering programs offer. Therefore, the presented results do not apply either to construction management programs or to programs other than civil engineering.

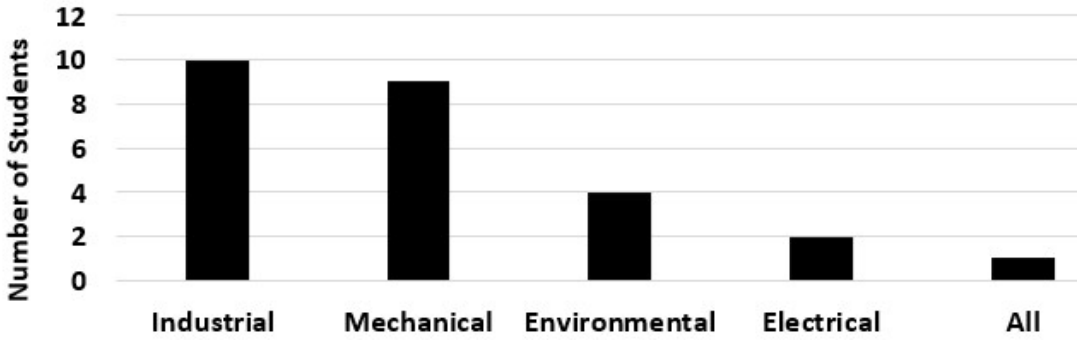

Figure 1: Students' perception on majors, other than civil engineering, benefiting from a construction engineering course

We reviewed the online catalogs of 200 undergraduate civil engineering programs. As Figure 2 illustrates, the institutions were selected so that there is some representation from all states. The catalogs showed that 147 universities (74%) offer a junior or senior course in construction. Fifty-seven out of 147 universities (39%) offer the course as mandatory and the remaining as elective. From the 147 universities, forty-eight (33%) also offer a Bachelor's in construction engineering, allowing the civil engineering students to select an elective among several construction engineering courses. From the fifty-three universities, which do not offer a construction engineering undergraduate course, twelve (23%) offer a separate construction management program in the college of engineering.

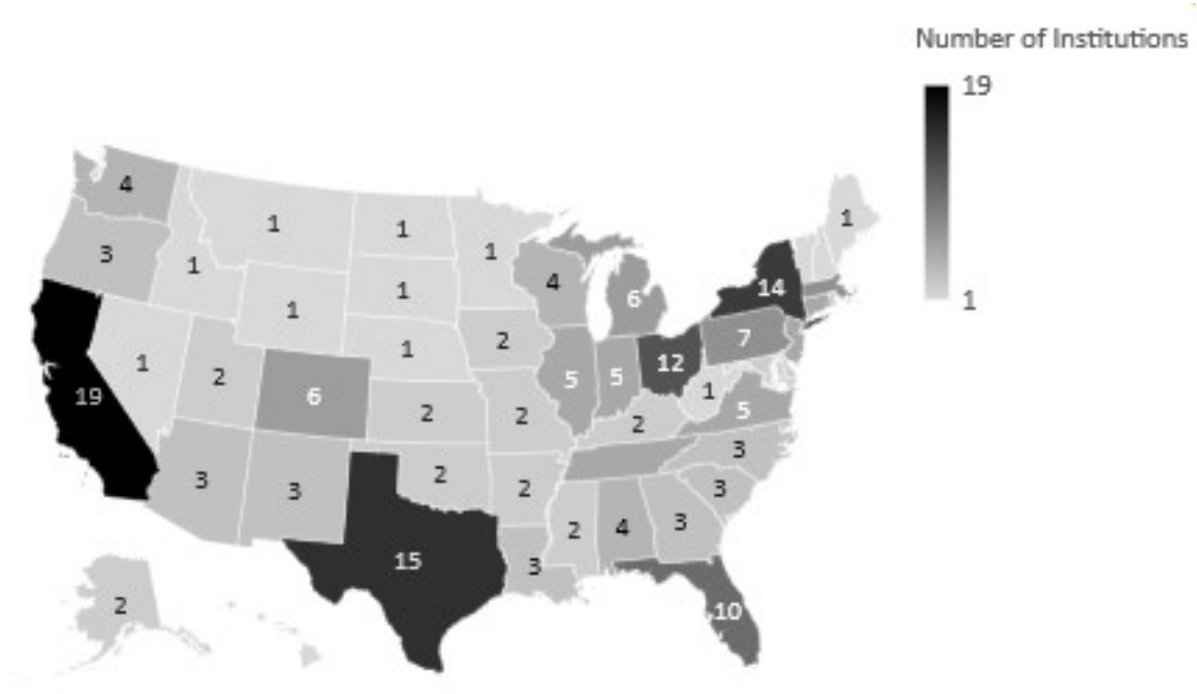

Figure 2: Location and number of universities

Figure 3 identifies the course names used by the civil engineering programs. It can be seen that "Construction Engineering," "Construction Management" and their variations, such as "Introduction to Construction Management," "Construction Engineering and Management," "Construction Project Management," are widely used. The construction engineering courses for civil engineering students have mostly three credit hours and only approximately 6% of the courses have two or four credit hours. The requirements for the course are junior/senior standing or the instructor's permission. Prerequisite courses, such as surveying, mechanics of materials, math, graphics, economics, or construction materials, are required by 22 (approx. 15%) of the 147 universities.

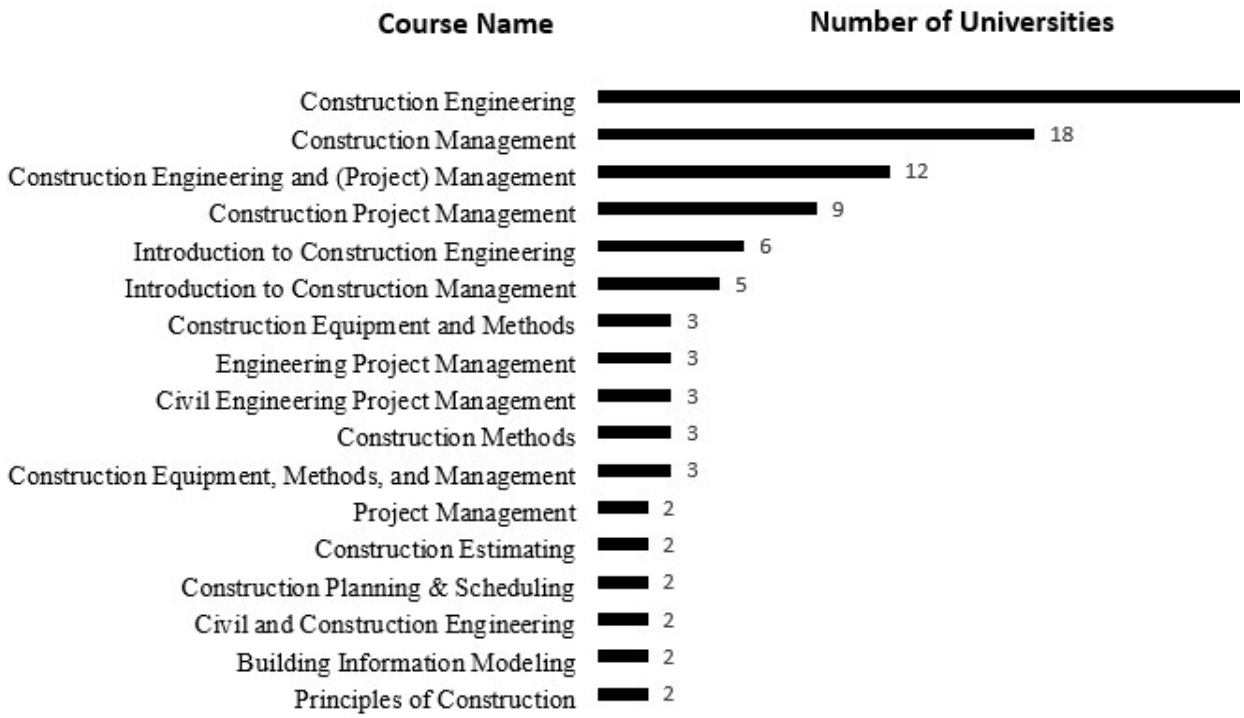

Figure 3: Most frequent course names

Methods and Results

For college graduates to successfully enter the professional practice of civil engineering, the civil engineering programs need to accomplish the student outcomes (SO) set forth by the Accreditation Board for Engineering and Technology (ABET) Criterion 3 [3] (see Table A-1 of the Appendix). ABET has also endorsed the Civil Engineering Program Criteria (CEPC) developed by the American Society of Civil Engineers (ASCE) [4] (see Table A-2 of the Appendix). Moreover, ASCE has developed its own Civil Engineering Body of Knowledge (CEBOK), which defines the knowledge, skills, and attitudes needed by the professional civil engineers [5]. The ASCE Body of Knowledge was developed over the past 15 years, and it provides the focus areas and related topics of the latest edition 3 (see Table A-3 of the Appendix). Previous studies compared the Body of Knowledge required by ASCE and ABET

[5, 6] and identified gaps such as the need of depth in a civil engineering area required by CEBOK and not by ABET.

Additionally, to become a professional engineer (PE), along with years of professional experience, civil engineers need to pass the civil engineering FE and PE exams. The civil FE exam has four to six questions out of 110 dedicated to construction, accounting approximately for 6% of the exam. The civil breadth of the PE exam has fourteen out of 40 questions relevant to construction in the areas of site development, project planning, means/ methods, and constructions codes totaling 35% of the breadth exam. When considering further the 40 questions in a concentration area, other than construction, the required knowledge in construction accounts for approximately 18% of the whole exam. Inclusion of topics such as ethics and professional practice, engineering economics, environmental regulations, materials, earthwork, and volume computations in a construction course can significantly increase the percentages reported above. The construction topics required by the National Council of Examiners for Engineering and Surveying are listed in Table A-4 of the Appendix [7, 8]. The check marks show which topics are required for the FE and the PE-Civil Breadth exams.

An online search identified the topics taught by the 147 universities, which offer a construction course in their civil engineering curriculum. These topics were retrieved from the online catalog descriptions of 180 courses. The number of courses (180) exceeds that of the universities (147), because some institutions offer more than one construction course as electives. Table 1 groups and ranks the topics. Planning/scheduling is the highest ranked topic and is used by the most construction courses. The percentage of courses out of 180, which cover the specific topics, are also presented in parentheses in the table. Topics covered by the same number of courses are given the same rank number. It should be again clarified that this study does not address courses offered by construction management programs. It specifically focuses on the construction courses offered to civil engineering students. Moreover, the collected information is based on the online catalog descriptions alone. It is well received that the content of the courses may change by the course instructors.

The topics referenced in the 180 courses in Table 1 address the requirements of ABET, ASCE CEBOK3, and NCEES (see Tables A-1, A-3, and A-4 of the Appendix, respectively). A designation is provided for each topic as: *CEBOK3_[ABET]_FE _PE*. For example, the designation "*T_[2,3]_Yes_Yes*" shows that the topic falls under the "Technical" category of ASCE CEBOK 3, "*T*"; it satisfies student outcomes 2 and 3 of Criterion 3 (see Table A-1of the Appendix) and it is listed as a required topic for both the FE and PE exams, ("*Yes*" for "required"). The designation "*EF_[6]_No_Yes*" means that the topic is included in the ASCE CEBOK 3 under the category "Engineering Fundamentals," "*EF*"; it contributes to ABET student outcome 6 of Criterion 3, and it is not required for the FE exam, but required for the PE exam.

Table 1: Course topics based on online search

Rank	Topic	Number of Courses	Designation *CEBOK3_[ABET]_FE_PE*
1	Planning/Scheduling	112 (62.2%)	*T_[1,5,3]_Yes_Yes*
2	Cost estimating /Budgeting	102 (56.7%)	*T_[1]_Yes_Yes*
3	Contractual/project delivery methods	85 (47.2%)	*P,T_[5,3]_Yes_No*
4	Fundamental concepts/definitions of construction industry (documentation: technical specifications, proposals, blueprint reading, change orders, construction drawings, etc.)	56 (31.1%)	*T_[3,4]_Yes_No*
5	Equipment (allocation, production, operation costs, fleet management, rigging design)	49 (27.2%)	*T_[1]_No_Yes*
6	Workforce/ Construction labor (pricing/agreements)	38 (21.1%)	*P,F_[1,3]_Yes_No*
7	Project management (owner/engineer/contractor)	35 (19.4%)	*T,P_[3,2,4,5]_Yes _No*
8	Safety / OSHA regulations	34 (18.9%)	*T,P_[2,3]_Yes_Yes*
9	Quality control & assurance/ inspection	33 (18.3%)	*P,T_[2,4]_No_Yes*
10	Construction materials (management/procurement/production)	30 (16.7%)	*EF_[6,7]_Yes_Yes*
11	Design and construction process	26 (14.4%)	*T_[1,2,3,5]_No_Yes*
12	Software and online databases for scheduling and cost-estimating (Primavera, Navisworks Manage, Spreadsheets, etc.)	21 (11.7%)	*T_[6,7]_Yes_No*
13	Resource allocation/management	19 (10.6%)	*P,F_[1,3]_Yes_No*
14	Project funding and cash flow	18 (10%)	*T_[2,4]_Yes_Yes*
14	Value engineering/Productivity	18 (10%)	*T_[2]_No_No*
15	Earthwork operations/excavations	16 (8.9%)	*T_[1,2]_Yes_Yes*
15	Engineering economics (rate of return, present /future worth)/financial control	16 (8.9%)	*T_[2,4]_Yes_Yes*
16	Risk estimation/uncertainty and management	14 (7.8%)	*T_[1,2,3,6]_Yes_No*
17	Construction of buildings, bridges, dams, highways, dams, etc.	12 (6.7%)	*T_[1,2,3,5]_No_Yes*
18	Building Information Modeling (Autodesk-Revit)	11 (6.1%)	*T_[2]_No_No*
18	Temporary structures (formwork, scaffolding, bracing)	11 (6.1%)	*T_[1,2]_No_Yes*
18	General code of conduct of engineers/Ethics/Professional liability	11 (6.1%)	*P_[2,4]_Yes_Yes*
19	USGBC'S green building certification/LEED Design/Sustainability/ Project life – cycle	9 (5%)	*T_[1,6]_No_Yes*
20	Quantity takeoff	7 (3.9%)	*T_[2,4]_Yes_No*

Rank	Topic	Number of Courses	Designation *CEBOK3_[ABET]_FE_PE*
21	Construction operations (blasting, dewatering, tunneling, soil stabilization, drainage, pressure piping, trenchless technology, aggregate production)	6 (3.3%)	*T_[1,2]_No_Yes*
22	Regulations/Codes (environmental)	5 (2.8%)	*T_[4]_Yes_No*
23	Decision making	4 (2.2%)	*TP_[1,4,6]_No_Yes*
23	Legal Management	4 (2.2%)	*P_[2,4]_No_No*
24	Site layout planning	3 (1.7%)	*T_[2,4]_No_Yes*
24	Leadership/teamwork	3 (1.7%)	*P_[5]_No_No*

Discussion

Considering the collected data for the 180 construction courses offered by the 147 US institutions in Table 1, one notices that the most addressed topics are the planning and scheduling, the cost estimating, the project delivery methods, the fundamental construction concepts, and the equipment. Only a few universities include topics such as leadership, legal management, and decision making in their syllabi. Several topics (e.g., earthwork operations) can be incorporated in other civil engineering courses. On the other hand, a few topics can constitute a course by themselves. Such examples are the construction materials, engineering economics, leadership, ethics, sustainability, and safety. The NCEES exams with some exceptions (e.g., legal management, BIM, value engineering) cover most of the topics in either their FE or PE exams. Some advanced topics, such as risk estimation, uncertainty management, sustainability, and value engineering are not addressed in the PE exam, while they are included in the FE exam. Most of the taught topics fall in the "Technical" category of the ASCE CEBOK 3. As Figure 4 shows, the topics taught satisfy primarily the ABET Criterion 3 student outcomes (SOs) 1 through 4 and with student outcomes 5, 6, and 7 being less addressed.

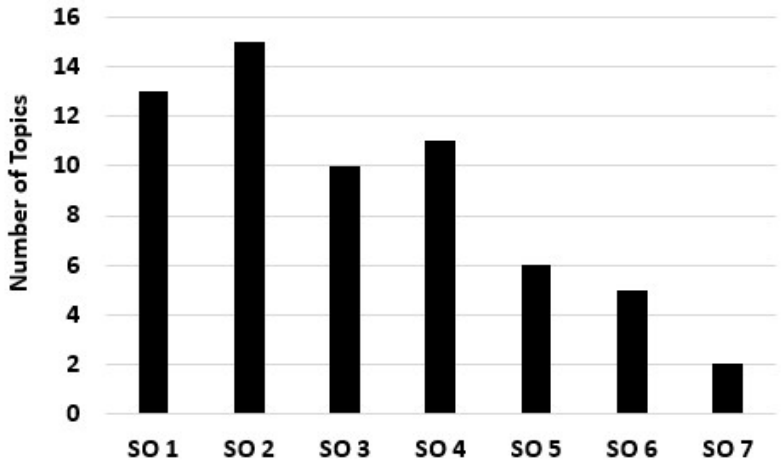

Figure 4: ABET Student Outcomes (SOs) addressed by the construction topics taught

Previous studies [9] suggested that undergraduate students can significantly advance their knowledge in the areas of project management/scheduling and estimating, teamwork, economic factors, and constructability through internships. However, this is only possible in urban areas, where there are usually firms looking for engineering interns. Collaboration of faculty with professional guest lecturers, and active participation in engineering societies such as ASCE could become beneficial alternatives and could supplement engineering education with real world experience. Several authors [10, 11] discussed ways of introducing sustainability in the engineering curriculum. Although sustainability can be a standalone course, there are some practical ways to thoroughly introduce sustainability (environmental, social, economic) in a construction engineering course. For example, including in the course a module with construction case studies, where students are asked to follow the principles of Envision [12] and/or Leadership in Energy and Environmental Design (LEED) [13] and adopt the more sustainable construction solutions.

Building a Construction Course

In this section, general guidelines are presented for building an undergraduate construction course for civil engineers, when the curriculum does not allow for several construction courses to be offered. Although the proposed content tries to systematically incorporate several of the topics presented in the study, the final selection of topics needs also to satisfy the ABET, ASCE, and NCEES requirements (see Table 1). The development of the course incorporates the sectors of preparation, development, and improvement [14] or alternatively skill attainment in levels [15]. The progressive accumulation of knowledge and skills is presented in Figure 5. The different levels of knowledge include the general topics listed in Table 1.

For students to achieve a satisfactory amount of construction knowledge, the course needs to incorporate topics from all the three levels of knowledge that are illustrated in Figure 5. The lower level that includes the fundamental construction concepts, planning/scheduling, cost, and budgeting, etc. agrees with Souder & Gierd [16], arguing that these topics provide knowledge that fulfill the industry's primary expectations for graduates. From the development level, selected topics should be included in a construction engineering course. As Table 1 shows, most institutions opt for the equipment, workforce, and project management topics. At the higher improvement level of knowledge selection of only few topics seems appropriate. Specialized material can contribute to the improvement of knowledge at the higher level. For example, the ASCE card [17] can contribute to gaining real world experience with the students set to find solutions for improving the crumbling US infrastructure. It is especially important to incorporate projects in a construction course that can significantly ameliorate the students' soft skills, such as leadership, creativity, and interpersonal skills [18, 19]. These projects can further help students gain knowledge on sustainability, risk estimation, and decision making.

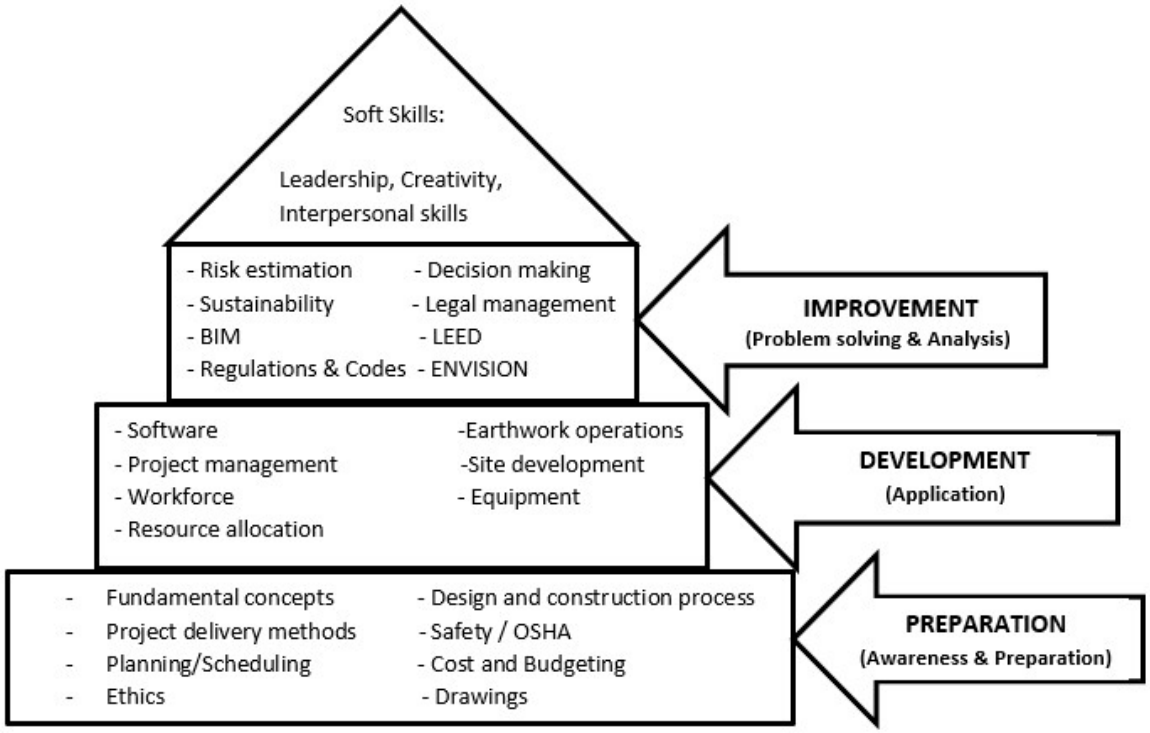

Figure 5: Layered construction topics for progressive knowledge acquisition

Conclusions

An online search of civil engineering programs and undergraduate catalogs of 200 US universities revealed that 29% of them offer a mandatory course in construction, 45% offer it as an elective, and 26% do not offer a course dedicated solely to construction. We identified and ranked the topics taught by examining the catalog descriptions of the 180 courses offered at the 147 institutions. The topics that most universities include in their catalogs are planning/scheduling, cost estimation, project delivery methods, documentation in construction, and equipment allocation and production.

We also examined the contribution of the taught topics to the requirements set by ASCE, ABET, and NCEES for future civil engineers to become successful professionals. We found that the FE and PE exams cover all the topics identified as "Technical" in the ASCE CEBOK 3. The ABET Criterion 3 student outcomes 1 through 4 are addressed more than other outcomes. We separated the construction topics into layers of knowledge, from fundamentals to problem solving and analysis topics. We proposed a combination of topics that needs to get reinforced by soft skills, projects, professional presentations, and real-world knowledge. Information depicted in this study encourages the inclusion of the course in more civil engineering programs. The presented material can be used for the development of new construction courses for civil engineering students or for the revision of existing courses.

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Appendix

Table A-1: ABET Criterion 3 Student Outcomes (SOs)

SO	Description
1	An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics.
2	An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
3	An ability to communicate effectively with a range of audiences.
4	An ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.
5	An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
6	An ability to develop and conduct appropriate experimentation, analyze, and interpret data, and use engineering judgment to draw conclusions.
7	An ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Table A-2: Current ABET Civil Engineering Program Criteria (CEPC)

The curriculum must prepare graduates to apply knowledge of:

- Mathematics through differential equations, calculus-based physics, chemistry, and at least one additional area of basic science.
- Apply probability and statistics to address uncertainty.
- Analyze and solve problems in at least four technical areas appropriate to civil engineering.
- Conduct experiments in at least two technical areas of civil engineering, analyze and interpret the resulting data.
- Design a system, component, or process in at least two civil engineering contexts.
- Include principles of sustainability in design; explain basic concepts in project management, business, public policy, and leadership.
- Analyze issues in professional ethics.
- Explain the importance of professional licensure.

Table A-3: ASCE Civil Engineering Body of Knowledge outcomes

Foundational (F)	Engineering Fundamentals (EF)
Mathematics	Materials Science
Natural Sciences	Engineering Mechanics
Social Sciences	Experiment Methods and Data Analysis
Humanities	Critical Thinking and Problem Solving
Technical (T)	**Professional (P)**
Project Management	Communication
Engineering Economics	Teamwork and Leadership
Risk and Uncertainty	Lifelong Learning
Breadth in Civil Engineering Areas	Professional Attitudes
Design	Professional Responsibilities
Depth in a Civil Engineering Area	Ethical Responsibilities
Sustainability	

Table A-4: Construction engineering topics for the NCEES exams

Topic	FE Civil	PE Civil Breadth
Construction documents	√	
Procurement methods	√	
Project delivery methods	√	
Construction operations and methods	√	√
Project scheduling	√	√
Project management (owner/engineer/contractor)	√	
Construction cost estimating	√	√
Quantity take-off methods		√
Temporary structures and facilities		√
Construction erosion control		√
Safety/OSHA regulations	√	√
Spreadsheet calculations	√	
Engineering economics	√	√
Environmental regulations		√
Earthwork and volume calculations	√	√
Ethics and professional practice	√	
Construction site layout and control		√
Materials	√	√
Probability and Statistics	√	
Sustainability &Sustainable Design	√	