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An Approach in Designing and Teaching Hands-on and Immersive Construction Cost Estimating Course

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Abstract

Construction projects require tools such as cost estimating to effectively control and manage them. Cost estimating is required at all phases of a project irrespective of the project delivery methods. Students enrolled in construction-related programs must be trained on how to quantify, price, and bid projects just the same way that practitioners do in real life. This requires crafting, designing, and teaching students hands-on and immersive construction cost estimating course(s). The main objective of designing and teaching a hands-on and immersive cost estimating course is to get the students ready from day one, by exposing them to the fundamentals of cost estimating. A review of cost estimating syllabi indicate a lack of consistency or standardization in the content covered. The literature on cost estimating as published in ASEE (American Society for Engineering Education) conference papers provide little or no examples of the typical cost estimating and bidding process. In addition, there are no samples from ASEE conference papers on the scope of work for quantity takeoff (QTO) and pricing assignments, or samples of the quantity takeoff templates, the pricing templates, and the criteria for grading students' work. This paper is written with all of that in mind and includes the estimating and bidding workflow, as well as the applicable templates. This paper presents a description and discussion of the approach for teaching construction cost estimating for both building construction projects and heavy civil construction projects. It is also hoped that other faculty in the construction-related programs could benefit from the description and discussion presented in this paper and aid them in implementing hands-on and immersive cost estimating courses in their programs.

Introduction

What do hands-on and immersive mean? – According to Kirk in [1], teaching and learning how to accurately estimate the cost of a project should follow an application-based methodology that mimics the basic processes that practitioners go through. Cost estimating has a set of processes that have not changed that much even in today's digital world using Building Information Modeling (BIM) technologies. Cost estimating is in part science and part art and should be taught using hands-on real-life methods. A review of cost estimating syllabi indicate a lack of consistency or standardization in the content covered. In addition, the literature on cost estimating as published in ASEE conference papers provide little or no example of the typical cost estimating workflow, and applicable templates for quantity takeoff, pricing, detailing the scope of work, and criteria for grading students' work.

Literature review

Cost estimating is the foundation of any construction organization, and a company's ability to prepare an accurate cost estimate will affect that company's ability to survive. Knowledge of cost estimating provides the foundation for other areas of construction project management to which students should be exposed to. For example, cost estimating touches on construction materials and methods, project planning and scheduling, cost control for field operation management, contract changes and claims management, and analysis and improvements to construction methodology.

A survey of how construction cost estimating is taught at the undergraduate level show that there is cost estimating for building construction projects and there is cost estimating for heavy civil construction projects, and within each of these areas, there is no consistency in the structure of the course content. Table 1 below details the typical content of construction cost estimating courses, and the table highlight

current practice. The survey was taken from 20 programs here in the US. Three of those programs focused on heavy civil construction cost estimating and the other 18 programs focused on building construction cost estimating.

Table 1. Typical content of construction cost estimating course as taught at various construction programs in the US.

TYPICAL COURSE CONTENT INCLUDED IN THE COURSE CALENDAR/SCHEDULE OF 20 CONSTRUCTION PROGRAMS	CMT234 Cost Estimating and Planning - Delaware Technical Community College -	CM3420 Construction Estimating and Bid Preparation - Kennesaw State University	CE 616-852 Construction Cost Estimating - New Jersey Institute of Technology	CMCE2412 Construction Estimating - New York City College of Technology	CME 380 Construction Cost Estimating - North Dakota State University	437 Heavy Construction Estimating - North Western University	CM232 Cost Estimating - South Dakota State University -	EM620 Engineering Cost Management - Stevens Institute of Technology	SIE-464-564-Cost Estimation - The University of Arizona	CE5379 Construction Cost Estimating - The University of Texas at Arlington	CE483-CE583 - Con Cost Estimating - University of Arizona	BCN-5618-Comprehensive Estimating - University of Florida - 2019 -	CNST 3365 Construction Cost Estimating for Capital Projects - University of	CONS 4008 4009 Cost Estimating - University of Lousiana, Monroe	CEM651 - Construction Estimating - University of Nevada, Los Veg	CE 506 Heavy Construction Estimating - University of Southern California 2018	CE4382_5382 Construction Cost Analysis and Bidding - University of Texas	CE5379 Construction Cost Estimating - University of Texas at Arlington	CE506 Heavy Construction Estimating - University of Southern California, Sonny	Virginia Tech - Est, Prod & Cost Engr
Pricing of Various Items of Work in the Assignments	YES	YES	YES	YES	YES	YES	YES	NO	NO	YES	YES	YES	YES	NO	YES	YES	YES	NO	YES	YES
Existing Conditions - Demolition Pricing Assignment																			X	
Earthwork Pricing Assignment	X			X	X		X			X	X	X	X		X		X		X	
Concrete Pricing Assignment	X	X	X	X	X		X			X	X	X	X		X	X	X		X	X
Masonry Pricing Assignment		X					X			X	X	X			X		X			X
Structural Steel Pricing Assignment					X		X				X	X	X		X					X
Wood Pricing Assignment					X		X				X	X			X		X			
Thermal and Moisture Protection Pricing Assignment					X		X					X					X			
Openings Pricing Assignment																	X			
Finishes Pricing Assignment							X					X					X			
Utilities Pricing Assignment															X	X			X	
Mechanical Pricing Assignment												X	X						X	
Electrical Pricing Assignment					X							X	X				X			
Plumbing Pricing Assignment					X							X	X				X			
Pavement Pricing Assignment				X	X										X	X			X	X
Tunnel Pricing Assignment						X													X	
Retaining Wall Pricing Assignment																X			X	
Marine Work Pricing Assignment																			X	
Bridge Pricing Assignment																			X	
Topic on Estimating and Bidding Process	NO	NO	NO	NO	YES	YES	NO	YES	YES	YES	YES	NO	NO	NO	YES	NO	NO	YES	NO	NO
Topic on Work Breakdown Structure (WBS)	NO	NO	NO	NO	NO	NO	NO	YES	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Topic on Direct and Indirect Costs	YES	YES	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	YES	NO
Topic on Types of Construction Cost Estimates	YES	YES	NO	YES	YES	NO	YES	YES	YES	NO	YES	YES	YES	YES	YES	NO	NO	YES	NO	YES

The data as shown below in Figure 1 provide a good picture of what is covered in construction cost estimating courses, and a closer look show gaps and a lack of consistency. For example, the topic on work

breakdown structure, and the topic on estimating and bidding process were not covered in the majority of the programs.

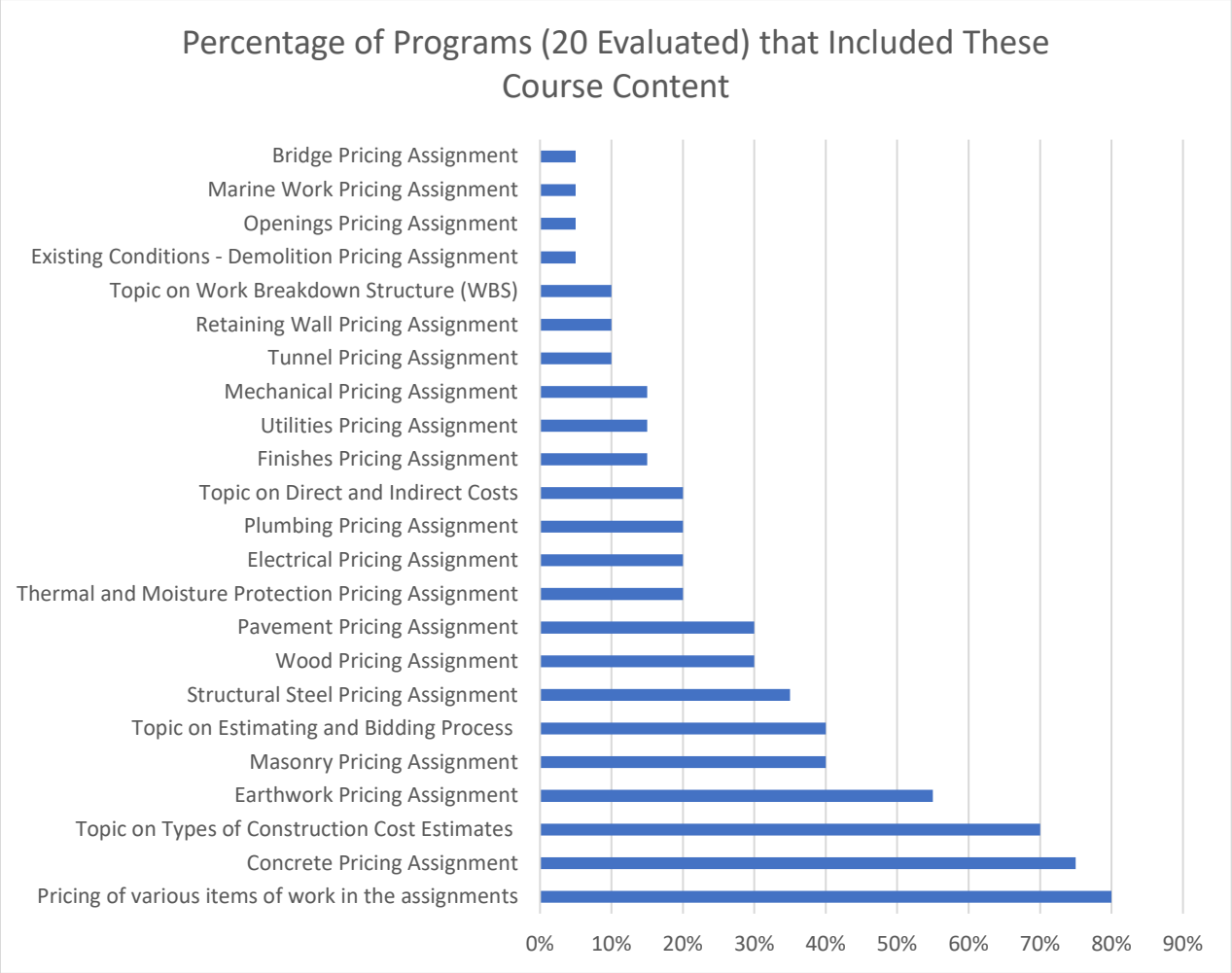

Figure 1. Distribution of typical content covered in construction cost estimating courses across construction programs in the US.

What is not known about the content covered in these courses is the level of exposure that is offered to the students since the design of the assignments is not known from the course calendar/schedule. The level of exposure could range from low-level to high-level exposure. Hence it is important to define in this paper the use of the word immersive. *Immersive in this paper is defined as a high-level exposure that allows students to deep-dive into project-based learning, aimed at preparing detailed quantity takeoffs and pricing of real-world project items of work following the same steps that an estimator working for a construction company would follow.*

Ressler and Lenox in [2] took an in-depth look at the ongoing specialization in civil engineering programs across the US, and one of their conclusions is that the programs should not create specialization if the knowledge and skills required for a given task area do not exceed the ability of an individual practitioner to acquire. While it may be beneficial to create specializations in a program, students must be grounded in core knowledge areas to help them collaborate and work with others. For example, working together on design-build projects may require a breadth of knowledge in several core areas.

Construction cost estimating as a mature field of study

According to Kuhn in [3], paradigm development refers to the extent to which a scientific field has well-defined rules or structure of knowledge. The word paradigm describes a common dimension of disciplinary fields. "Mature" disciplines of study relate to those well-developed paradigms such as physics, chemistry, statics, strength of materials, and structural analysis, that are known to have unambiguous ways of defining, ordering, and investigating knowledge in those areas. The preparadigmatic areas are the opposite of the mature areas of knowledge. Those are the areas that have high levels of variations on content as to what constitutes new knowledge, what constitutes appropriate methods for inquiry, what standards are applied to determine acceptable findings, what inquiries are proven or yet to be proven, and what defines an important problem to be pursued.

Popper in [4] differentiates theory from experience and writes in the logic of scientific discovery that empirical methods are characterized by practical experience based on known and repeatable (reproducible) methods or procedures. Practical experience as different from theory is exemplified in the field of construction where the construction of projects is based on practical experience about how things are done. Cost estimating is a mature field, it follows well-defined steps based on practical experience.

The basic process of cost estimating and bidding

Figure 2 below was adapted from Okere and Kirk in [5] and details the processes related to detailed cost estimating and bidding specifically to design-bid-build delivery methods. This becomes the framework to guide what students need to learn to be able to accurately produce detailed cost estimates for bids related to design-bid-build projects. This also means that students must learn about other estimating methods different from detailed cost estimates, and they should also be taught about project delivery methods. As such the course content should cover the processes detailed below as well as the different cost estimating methods and the different project delivery systems used in construction as they apply in cost estimating.

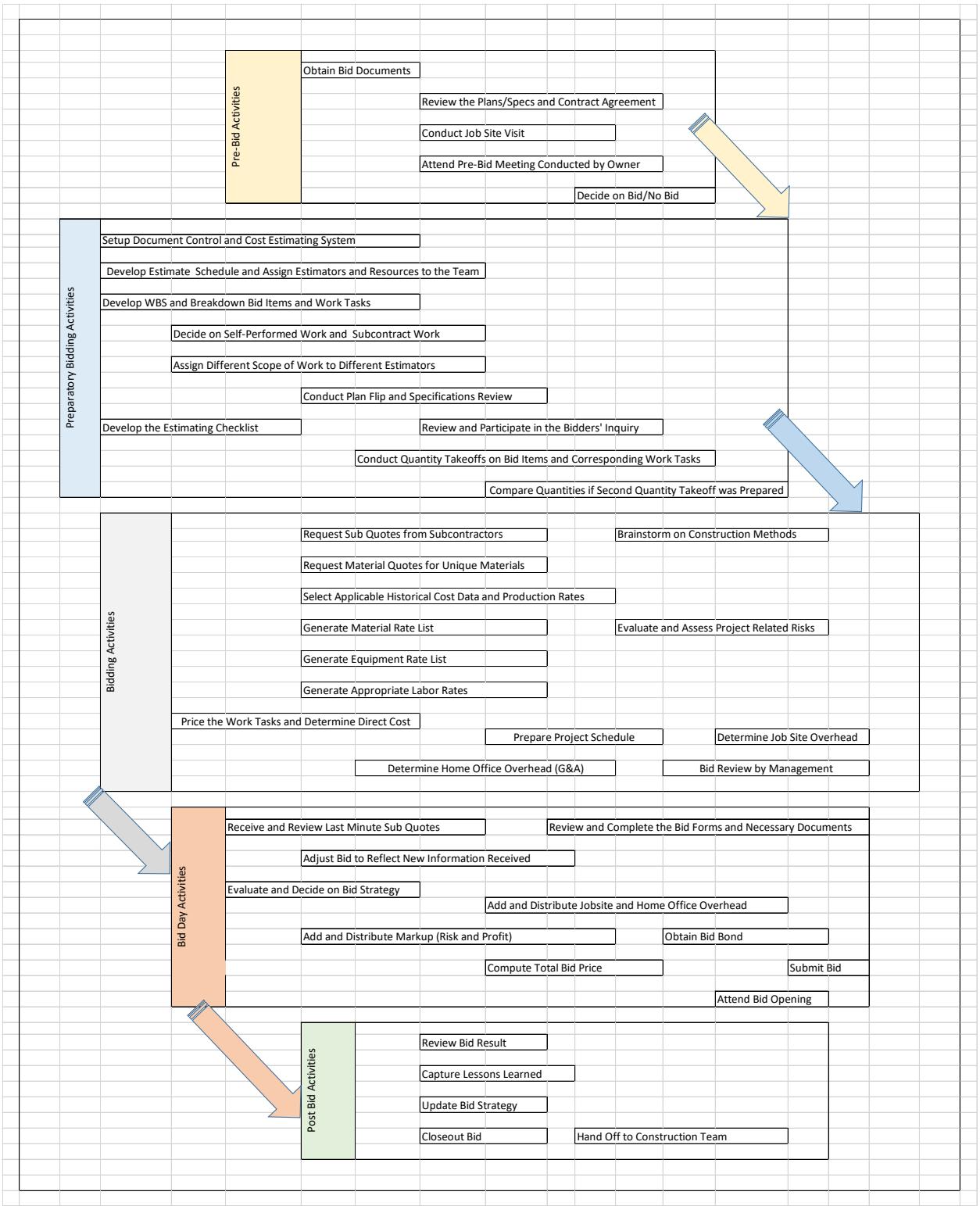

Figure 2. Cost estimating and bidding processes for design-bid-build projects -Adapted from Okere and Kirk's in [5]

One thing that is obvious with the cost estimating and bidding process presented above is that it captures the typical processes that construction companies go through irrespective of whether they are bidding on building construction projects or heavy civil construction projects. What is different is the type of drawings that are typical of building construction projects or heavy civil construction projects.

The approach in designing and teaching hands-on and immersive construction cost estimating courses

Based on the key processes, the course content follows and reinforces the cost estimating and bidding processes. The course structure, content, and design are presented below. The authors teach cost estimating for building construction projects and cost estimating for heavy civil construction projects. Table 1 below shows the topics covered in both courses. However, the key difference is that the examples used, in-class exercises, assignments, and exams are focused respectively on either building construction projects or heavy civil construction projects. Table 2 below is an outline of the topical area covered in both courses in the first half of the semester.

Table 2. Topical area covered in cost estimating for building construction projects, and heavy civil construction projects.

Typical Topics Covered in Both Courses
Construction Industry Characteristics with emphasis on Project Lifecycle,
Refresher on Construction Project Types, Components, Materials and Methods
Types of Cost Estimates and Their Accuracy Level
Methods for Obtaining Contract, Project Delivery, Contract Payment, and Bonds
Construction Documents Used in Cost Estimating for Bid/Proposal Preparation
Cost Estimating Processes and Steps
Sources, Groups, and Factors that Drive Construction Costs
Engineering Economy
Breaking Down and Aggregating Bid/Pay Items (Line Items), and Breaking Out the Items of Work into Corresponding Materials and Work Tasks
Fundamentals of Blueprint (construction drawings) Reading
Measurement and Quantity Takeoff for Work Task and Materials
Fundamentals of Specifications Reading

Students usually take the materials and methods courses before taking the cost estimating course, but in some programs, this may not be a requirement for civil engineering students. To help bridge this gap and also provide a refresher, a lecture or two is added to expose students to the various types of construction projects and their applicable components. In addition, students may be directed to complete some exercises at https://constructiongame.ceas5.uc.edu/, a publicly accessible and free construction-related knowledge website configured and maintained by Dr. Okere at the University of Cincinnati. The website is a construction knowledge-focused website, aimed at helping students and young professionals brush up and fill learning gaps on various construction-related knowledge paths. A good understanding of cost estimating must be grounded in knowledge of the project, the project components, the component materials, and the construction methods for incorporating those component materials into the project.

The concept of work breakdown structure (WBS) is very important because it affects how the bid/pay items are grouped and aggregated, and how they are subsequently broken down for detailed quantity takeoff and pricing. This is an area to highlight the concept of level of detail, and why construction companies develop and maintain a master list of tasks for consistent historical cost data collection and

use. In addition, this is also a good place to provide further discussion about the use and application of Uniformat II and MasterFormat as a form of WBS. The basics of WBS can be summarized in different ways and levels of detail used in presenting and breaking down the scope of work. Figure 3 provides the many ways and levels of detail.

Figure 3. Options for grouping, detailing, aggregating, and breaking down the project scope of work.

Another topic that is worth describing is construction costs as broken down by direct costs and indirect costs with examples of algorithms behind direct cost computation. Figure 4 details the breakdown of construction costs, and Figure 5 details how direct costs are computed.

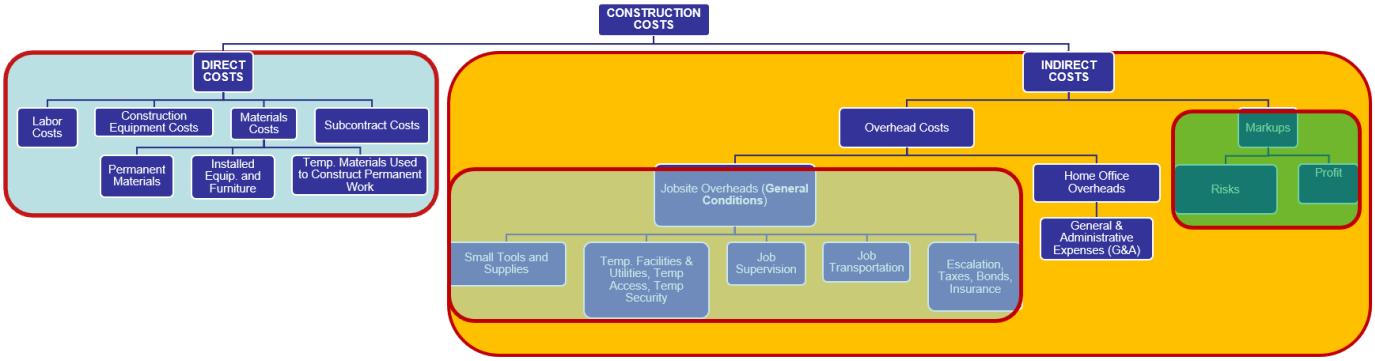

Figure 4. Breakdown of construction costs.

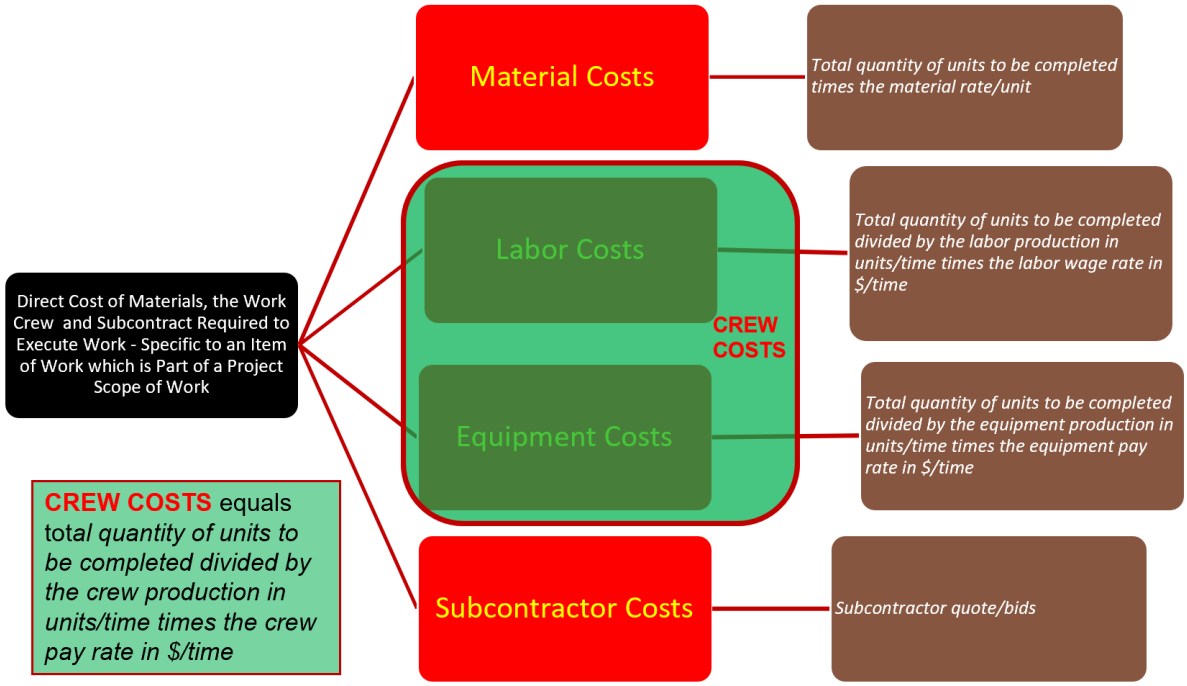

Figure 5. Breakdown of direct costs computation.

For the building construction project estimating course, table 3 below captures the areas and divisions that the course focuses on for the second half of the semester.

Table 3. List of areas of focus for weekly hands-on and immersive exercises.

Weekly Hands-on Exercises for the Building Construction Cost Estimating Course
Detailed Cost Estimate for Division 02 (Existing Conditions) Items of Work – Scoping, Itemize Work Tasks, QTO, and Pricing of Items of Work
Detailed Cost Estimate for Division 31 (Earthwork) Items of Work – Scoping, Itemize Work Tasks, QTO, and Pricing of Items of Work
Detailed Cost Estimate for Division 03 (Concrete) Items of Work – Scoping, Itemize Work Tasks, QTO, and Pricing of Items of Work
Detailed Cost Estimate for Division 05 (Metals) Items of Work – Scoping, Itemize Work Tasks, QTO, and Pricing of Items of Work
Detailed Cost Estimate for Division 32 (Exterior Improvements) Items of Work – Scoping, Itemize Work Tasks, QTO, and Pricing of Items of Work
Detailed Cost Estimate of Precast Box Culvert Project Items of Work – Various Divisions – Scoping, Itemize Work Tasks, QTO, and Pricing Items of Work

Each week, the course focuses on one specification division with select bid/pay items. This was done not to overwhelm the students, but to allow them to estimate a few items that will challenge and expose them to the basic steps required to properly quantify and price out the items of work. Because the class has one week to complete the items of work assigned to them, the scope of work was carefully crafted and detailed to help the students complete their work for each section within one week. Information about the items of work to be estimated, the reference drawings to review, and the applicable construction method detailing the tasks, and materials were provided. In addition, the reference cost data were provided. Table 4 is an example of the scope of work for division 03 concrete work.

Table 4. Example of the scope of work for division 3 – concrete work.

BID/PAY ITEM NUMBER	CONCRETE WORK	**UOM**	**Reference Cost Data Division**
23	***Reinforced Concrete Shear Wall*** Between Level 01 and Level 02 of **Area A** a. Procure shear wall formwork material (SF) b. Place & strip shear wall formwork (SF) c. Procure reinforcement bars for the shear wall (TON)– assume rebar occupies 5% space of shear wall volume. Convert to tons based on the fact that the unit weight of steel is 490 pounds per cubic foot (ft3). Note that 2000 pound = 1 Ton d. Fabricate & install reinforcement bars for the shear wall (TON) e. Procure concrete (of specified strength per page 03-30-00-11 of the CAST-IN-PLACE CONCRETE specifications) - (CY) f. Pour shear wall concrete (CY) g. Cure shear wall concrete (CSF) h. Dry Finishing (SY) i. Miscellaneous items such as embeds and sandblasting	Refer to each work task for their respective UOM	Refer to reference cost data
24	***Precast and Cast-in-place Concrete Columns*** Between Level 01 and Level 02 of **Area A.** Quantify and price out only 11 columns located at the following gridlines: X1-7; X1-8; O-7; 0-8; M-8; M-13; M-15; V8-W2; V8-W3; W2-15; W3-15 (*Note that the square columns are cast in place and the round columns are precast*) a. Procure square column formwork material (SF) b. Place & strip square column formwork (SF) c. Procure reinforcement bars for square columns (TON) – assume rebar occupies 5% space of square column volume. Convert to tons based on the fact that the unit weight of steel is 490 pounds per cubic foot (ft3). Note that 2000 pound = 1 Ton d. Fabricate & install reinforcement bars for square columns (TON) e. Procure concrete (of specified strength per page 03-30-00-11 of the CAST-IN-PLACE CONCRETE specifications) for square columns (CY) f. Pour square column concrete (CY) g. Cure square column concrete (CSF) h. Dry Finishing (SY) i. Miscellaneous items such as embeds and sandblasting j. Procure precast round columns (of specified strength per page 03-30-00-11 of the CAST-IN-PLACE CONCRETE specifications) and deliver to site (LF) k. Install precast round columns as specified (LF)	Refer to each work task for their respective UOM	Refer to reference cost data
25	***5" Thick Reinforced Concrete Slab-on-grade*** At Level 0 (Basement) of **Area A**. a. Procure slab-on-grade formwork material (LF) b. Place & strip slab-on-grade formwork (LF) c. Procure WWF reinforcement for concrete slab-on-grade (CSF) d. Fabricate & install WWF reinforcement for concrete slab-on-grade (CSF) e. Procure concrete (of specified strength per page 03-30-00-11 of the CAST-IN-PLACE CONCRETE specifications) for concrete slab-on-grade concrete– (CY) f. Pour slab-on-grade concrete (CY) g. Finish slab-on-grade concrete surface. Finish to be bull float, manual float, & broom finish, w/edging & joints (SF) h. Cure slab-on-grade concrete (CSF) – use the top surface area of the top of the slab on grade i. Dry Finishing (SY) j. Miscellaneous items such as embeds and sandblasting	Refer to each work task for their respective UOM	Refer to reference cost data

For cost estimating the heavy civil construction projects, Table 5 shows the areas and divisions that the course focuses on for the second half of the semester.

Table 5. List of areas of focus for weekly hands-on and immersive exercises.

Weekly Hand-on Exercises for Heavy Civil Construction Cost Estimating Course
Detailed Cost Estimate for Roadway Items of Work - Scoping, Itemize Work Tasks, QTO, and Pricing of Items of Work
Detailed Cost Estimate for Erosion Control Items of Work - Scoping, Itemize Work Tasks, QTO, and Pricing of Items of Work
Detailed Cost Estimate for Drainage Items of Work - Scoping, Itemize Work Tasks, QTO, and Pricing of Items of Work
Detailed Cost Estimate for Pavement Items of Work - Scoping, Itemize Work Tasks, QTO, and Pricing of Items of Work
Detailed Cost Estimate for Retaining Wall Items of Work - Scoping, Itemize Work Tasks, QTO, and Pricing of Items of Work
Detailed Cost Estimate for Bridge #1292 Items of Work - Scoping, Itemize Work Tasks, QTO, and Pricing of Items of Work

Similar to the format for the cost estimating for building construction projects, the course was designed to focus on a few bid/pay items. For roadway, erosion control, drainage, pavement, and retaining wall items of work, the scope was written using station numbers to indicate a limit detailing the roadway alignment and beginning station to ending station. For the bridge work, not all the items were assigned to the students, only a few of the major items of work were assigned as shown in Table 6.

Table 6. Sample of the scope of work for a bridge replacement project.

ITEM #	ITEM CODE	0019 BRIDGE – HAM 75-1292	UOM	BID QUANTITY		Reference Cost Data Division
0576	505E11100	PILE DRIVING EQUIPMENT MOBILIZATION (WT: NR)	LS	1.00		Refer to reference cost data
0577	507E00500	12" CAST-IN-PLACE REINFORCED CONCRETE PILES, DRIVEN (WT: 53)	FT	5,430.00		Refer to reference cost data
0578	507E00551	12" CAST-IN-PLACE REINFORCED CONCRETE PILES, FURNISHED, AS PER PLAN (WT: 53)	FT	5,920.00		Refer to reference cost data
0579	507E00600	14" CAST-IN-PLACE REINFORCED CONCRETE PILES, DRIVEN (WT: 53)	FT	3,575.00		Refer to reference cost data
0580	507E00651	14" CAST-IN-PLACE REINFORCED CONCRETE PILES, FURNISHED, AS PER PLAN (WT: 53)	FT	3,900.00		Refer to reference cost data
0581	509E10000	EPOXY-COATED REINFORCING STEEL (WT: 23)	LB	280,986.00		Refer to reference cost data
0582	511E34447	CLASS QC2 CONCRETE WITH QC/QA, BRIDGE DECK, AS PER PLAN (WT: 21)	CY	504.00		Refer to reference cost data
0583	511E41013	CLASS QC1 CONCRETE WITH QC/QA, PIER ABOVE FOOTINGS, AS PER PLAN (WT: 21)	CY	75.00		Refer to reference cost data
0584	511E44113	CLASS QC1 CONCRETE WITH QC/QA, ABUTMENT NOT INCLUDING FOOTING, AS PER PLAN (WT: 21)	CY	313.00		Refer to reference cost data
0585	511E46512	CLASS QC1 CONCRETE WITH QC/QA, FOOTING (WT: 21)	CY	431.00		Refer to reference cost data
0588	512E33000	TYPE 2 WATERPROOFING (WT: 40)	SY	19.00		Refer to reference cost data
0589	513E10260	STRUCTURAL STEEL MEMBERS, LEVEL 3 (WT: 24)	LB	458,724.00		Refer to reference cost data
0590	513E20000	WELDED STUD SHEAR CONNECTORS (WT: 25)	EA	5,097.00		Refer to reference cost data
0594	516E11210	STRUCTURAL EXPANSION JOINT INCLUDING ELASTOMERIC STRIP SEAL (WT: 27)	FT	186.00		Refer to reference cost data
0595	516E13600	1" PREFORMED EXPANSION JOINT FILLER (WT: NR)	SF	140.00		Refer to reference cost data
0596	516E44201	ELASTOMERIC BEARING WITH INTERNAL LAMINATES AND LOAD PLATE (NEOPRENE), AS PER PLAN10"X14"X3.0629" WITH 11 1/4"X15 1/4"X1 3/4" LOAD PLATES (WT: 21)	EA	9.00		Refer to reference cost data

The template for quantity takeoff and pricing was designed specifically to make the process more intuitive and to emphasize the importance of detailed, easy-to-follow, and transparent quantity takeoffs. Both courses relied heavily on the use of cost data for material pricing, crew composition, crew daily output, and crew bare cost. Table 7 is the template that was developed for quantity takeoff for applicable work tasks, and Table 8 is the pricing template that was developed for pricing the corresponding work tasks.

Table 7. Quantity takeoff (QTO) template.

Completed By		Project Name	
Checked By		Bid Item Number(s)	

						DIMENSIONS												
Reference Drawing Sheet Numbers	Reference Specification Division/Sections	Project System	Bid/Pay Item Number	Description of Work Tasks and Materials Quantified	*UNIT OF MEASURE (UOM)*	*NUMBER OF SIMILAR UNITS (Count)*	*LENGTH*	*WIDTH*	*HEIGHT (THICKNESS or DEPTH)*	*PERIMETER*	*DIAMETER*	*AREA*	*VOLUME*	*DENSITY (UNIT WEIGHT)*	*WEIGHT*	*SUBTOTAL QUANTITY*	*TOTAL QUANTITY (Must be in the same UOM as the Unit of Measure Column)*	Comments/Side Notes
					UOM	EA	FT	FT	FT	FT	FT	SF	CF	LB/CF	TON			

Table 8. Pricing template.

Completed By							Project Name											
Checked By							Bid Item Number											
							Material Cost			***Crew Daily Output, Crew Daily Cost, Duration of Work, and Crew Cost***				*Sub Cost*	*Total Direct Cost*	*Other Cost*		
Reference Drawing Sheet Numbers	Reference Specification Sections	Bid/Pay Item Number	Reference Cost Data Line Item Number	Description of Work Tasks and Materials Quantified	Unit of Measure (UOM)	Total Quantity	*Material Unit Cost*	*Material Total Cost*	*CREW ID No.*	*Crew Daily Output (Unit/Day)*	*Crew Daily Cost ($/Day)*	*Duration of Task (in Days)*	*Crew Total Cost*	*Subcontractor Cost*	*Total Direct Cost for Each Task*	*Other Cost - Overheads (Jobsite and Home Office) and Markup*	*Total Price for Bid Item*	Indicate Who Priced Out What Item of Work

Using today's technologies in teaching construction cost estimating is important, and a range of technologies are used to simulate reality. Excel spreadsheet is used for the quantity takeoff sheet and pricing sheet, and students are encouraged to improve their skills in using Excel spreadsheet which is one of the most widely used digital tools in the construction industry. Digital construction drawings and specifications were used in all cases, Bluebeam license is made available to students, and it is used for reading drawings and for quantity takeoffs. Cost estimating software is also introduced to the students for

students to learn to transition from using Excel spreadsheets to estimating software. Students go through the following steps while working with the estimating software:

1. Create a new job (estimate)
2. Update the job properties
3. Enter the applicable item of work – pay/bid items
4. Enter the corresponding subordinate cost item(s) of work related to each pay/bid item
5. Update and add required labor and equipment resources to the applicable resource rate table
6. Update and add required material resources to the material rate table
7. Update and add applicable crew to the crew assembly table
8. Insert the required crew assembly and materials into the corresponding cost item
9. Enter crew daily output for the crew assembly assigned to a cost item
10. Understand how to make adjustments for the job site overhead and home office overhead
11. Review the pay/bid item to make sure that they are properly populated
12. Export the corresponding tasks to Microsoft Project for use in creating a project schedule
13. Run and print reports

Where available a 3D PDF model of the project being estimated is provided to the students to help them to visualize the project. The learning management system (LMS) is set up and used for students to access all the documents that they need for completing their QTO and pricing. The discussion feature on the LMS platform is used to simulate bidders' inquiry and the students use it extensively to post their questions and seek clarification. In addition, the students follow the due date and time to turn in their QTO and pricing sheet, and an assignment folder is created in the LMS system for the students to turn in their work.

During the second part of the semester when the students start the hands-on and immersive exercises, the class was broken into teams of 3. Teams of 3 are chosen to allow each student to be fully engaged in the QTO and pricing process. Each team also has a lead estimator specific to each division estimated, and the lead estimator's role is to compile and turn in the team's QTO sheet, and pricing sheet.

The grading rubric as shown in Table 9 and Table 10 is designed to evaluate students' work and allow them to see where they needed improvements. One major change to the grading of QTO and pricing process is the implementation of self-grading by the teams. Over the years it became clear that the teams were not paying attention to the review comments that were provided weekly regarding the QTO and pricing sheet, and self-assessment was chosen as a better option because it allowed for self-examination. Self-assessment has been found to have several benefits and help make individuals better team players (Gehringer in [6]).

Table 9. Grading rubric level 1.

CHECKLIST AND GRADING RUBRIC FOR SELF-ASSESSMENT AND GRADING OF THE TEAM'S QTO and PRICING	YES/NO	Points to Deduct if NO	
1. Does your team's QTO and pricing sheet include all the items of work listed in the scope of work?		0.5	LEVEL ONE
2. Did your team itemize and breakdown each item of work into their respective tasks?		0.5	
3. Did your team accurately quantify each of the tasks based on the UOM specified and used in the corresponding reference cost data line item?		0.5	
4. Within the orange color area of the QTO, are all the dimensions in the cells aligned with the unit of measure shown at the top of the column for each cell?		0.5	
5. Within the green color area of the QTO, are the dimensions in the cells aligned with the UOM as noted in the UOM column?		0.5	
6. Did your team use the right reference cost data crew for pricing tasks that are completed by a crew?		0.5	
7. Did your team use the crew's bare cost per self-performed work (not including subcontract overhead & profit) for your crew's daily costs?		0.5	
8. Is the duration for the tasks correctly calculated (and not rounded up or down), as the total quantity of work to be completed divided by the crew's daily output?		0.5	
9. Did your team only include material cost under the materials column for items that did not require procurement of construction materials?		0.5	
10. When not included in the scope of work, did your team make sure that there is no cost added in the overhead and markup column of the pricing sheet?		0.5	
11. Did your team include the screenshots for all the crew IDs that you used in your pricing sheet?		0.5	
12. In the pricing sheet and under the columns named accordingly, did your team include the name of the team member who completed the QTO and pricing for each item of work?		0.5	
13. Did your team organize the items of work in your QTO and pricing sheet to follow the order of the numbering you saw in the scope of work?		0.5	
14. Did your team include the total at the bottom of the pricing sheet showing the combined total of all the items that your team priced?		0.5	
15. Did your team add a row (as a divider) between the items of work and shade that row black or a color of your choice?		0.5	
16. In your QTO did your team include the reference drawing sheet number, specifications number, and the bid/pay item number?		0.5	
17. In your pricing sheet, did your team include the reference cost data line item number that your team used to price the items?		0.5	

Table 10. Grading rubric level 2.

CHECKLIST AND GRADING RUBRIC FOR SELF-ASSESSMENT AND GRADING OF THE TEAM'S QTO and PRICING	YES/NO	Points to Deduct if NO	
1. Did your team turn in the QTO and pricing sheet on time and before the due date and time?		4	LEVEL TWO
2. Did your team complete the estimate for all the bid/pay items?		# of Bid/Pay not estimated divided by total # of Bid/Pay Items to be estimated times 20	
3. In your QTO for each task that you computed the quantity, did your team accurately show only dimensions that contribute to the required quantity for each task you measured, and made sure that unnecessary and confusing dimensions were not shown?		4	
4. Was your team's combined total cost from all your bid/pay items within the accuracy range of + - 11% of the combined total cost as shown in the solution provided in class?		5	
5. Was your team's total cost for each bid/pay item within the accuracy range of +- 11% of the bid/pay item total cost as shown in the solution provided in class?		2	

It is also important to remember that team dynamics, conflicts, and issues may differ from team to team. One of the major issues is when a team member is late at getting his or her portion of the assignment completed, and the lead estimator has to wait on him or her to quickly compile and turn in the team's work. Another issue is where the grading of a team is affected by the quality of QTO and pricing completed by a team member. Working in teams offer students the unique opportunity to learn to work with others – just as it is in real-life project situations. In addition, students get to learn soft skills that are sought after by construction companies. No other opportunity prepares students to learn soft skills than when they work on team projects. Soft skills are a combination of people skills, social skills, communication skills, personality traits, attitudes, social intelligence, and emotional intelligence, among others. Soft skills enable people to navigate their environment, work well with others, and perform well.

Conclusion and recommendations

Students enrolled in construction-related programs must be trained on how to quantify accurately and confidently, price out, and bid projects just the same way that professionals do it in real life. This requires that educators learn to craft, design, and teach hands-on and immersive construction cost estimating course(s). The main objective of designing and teaching a hands-on and immersive cost estimating course is to get the students ready from day one. A review of cost estimating syllabi in the US indicate a lack of consistency or standardization in the content covered. In addition, the literature on cost estimating as published in ASEE conference papers provide little or no examples of the typical cost estimating workflow, and applicable templates for quantity takeoff, pricing, detailing the scope of work, and criteria for grading students' work. This paper presented the cost estimating and bidding workflow, as well as the applicable templates. This paper discussed an approach for teaching construction cost estimating for both building construction projects and heavy civil construction projects.

Cost estimating is currently taught at most universities with one course dedicated to building construction projects and another dedicated to heavy civil construction projects. The fact that we can not predict the career path of a student going into the residential building sector, commercial building sector, industrial sector, or heavy civil sector, it might not be a bad idea for students to learn both areas of cost estimating. This could mean a 4-unit course or two separate courses. This idea is exemplified by ASCE's design of a 2-day construction cost estimating training https://www.asce.org/-/media/files/customized-group-training/construction-cost-estimating.pdf in [7] designed as a mix of knowledge in both building projects and heavy civil projects. Similarly, like the format reported by Sase and Wei in [8], at California State Polytechnic University, Pomona, students take two estimating courses. This is similar to the format at California State University, Chico. The first course is focused on building construction estimating, and the second course is focused on estimating heavy civil construction projects.

The authors have taught cost estimating courses over the years and have not yet found the need to recommend or require a textbook for students. However, the author often consults the extensive literature on cost estimating, knowing that each author presents content from a different perspective – some easy to understand and others not so clear. In other words, consult the literature to get different perspectives on how best to craft, present and teach the course. Textbooks sometimes get in the way of good teaching.

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