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Online Course Design for the Engineering Workforce: Bringing Theory to Practice

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ABSTRACT

This paper describes the course design and evaluation results for an online continuing education program designed for working engineers. Engineering educators have long recognized the value of reducing the gap between the classroom and work environments. Implementing experiential learning in the undergraduate classroom brings much needed context to engineering students who may otherwise lack these real-world opportunities. Continuing education programs face the opposite challenge, where educators strive to bring the course content to working engineers who are already enmeshed in real-world contexts. This program was designed for busy working professionals and contextualizes theoretical concepts of Finite Element Analysis (FEA) with practical application of digital engineering tools. Online delivery enables engineers to learn while remaining in the context of their work environment. The authors describe their collaboration process in the design of this continuing education course. Course survey results provide data to evaluate the course design and to better understand how this nontraditional audience uses continuing professional development courses to stay abreast of technological change. Learners indicated through their survey responses that the course was a positive experience and met their learning goals. However, most students did not continue with the multi-course certificate program and left the program after only one course completion. Higher education institutions are uniquely positioned to create courses and programs that aid this nontraditional audience, the engineering workforce, in adapting to continuously changing technology and engineering practice. This paper presents lessons learned and recommendations for engaging with the community of working engineers as continuing education learners.

Key words: Online, professional development, project-based learning

INTRODUCTION

Engineering educators have long recognized the value of reducing the gap between the classroom and the engineering workplace. Introducing project-based learning (PBL) strategies into the undergraduate engineering curriculum is one method to reduce this gap and support the development of problem-solving capabilities of students. PBL strategies present problem context so that students can acquire knowledge and develop problem-solving skills (Hmelo-Silver 2004; Albanaese and Mitchell 1993). There are various and wide-ranging definitions of PBL which illustrate that it is not a single universal method, but one helpful working definition of PBL is:

> "the learning that results from the process of working toward the understanding or resolution of a problem. The problem is encountered first in the learning process and serves as a focus or stimulus for the application of problem solving or reasoning skills, as well as for the search for or study of information or knowledge needed to understand the mechanisms responsible for the problem and how it might be resolved" (Barrows and Tamblyn 1980 p.18).

Project-based learning and problem-based learning are often used interchangeably, but slight differences are highlighted here. In problem-based learning, students are asked to present a solution to a clearly defined problem, where project-based learning strategies challenge students to generate an artifact to demonstrate mastery of course concepts (Savery 2006). For working engineers, project-based learning aligns with these learners' abilities to bring complex and ill-defined problems to the learning environment. These learners are uniquely positioned to use these challenges to demonstrate proficiency in the underlying concepts.

There are multiple strategies that can be implemented to reduce the gap between the workplace and the engineering classroom. For traditional engineering students, the techniques focus on bringing real-world problems and contexts to the classroom. For nontraditional audiences such as working professionals, innovative methods that honor learners' real-world engineering experiences should be considered. Rather than bringing the context to the classroom, these learners benefit from instructional designs which bring the classroom to the workplace to leverage the abilities of these learners to apply their own workplace challenges as they engage with higher education programs.

Another trend in engineering education is the diversification of students in higher education programs, specifically an increase in nontraditional student enrollments (Cantwell et al. 2001). One example of nontraditional students engaging with higher education programs stems from the engineers already in the workplace seeking resources to help them cope with new tools and methods brought about by advances in technology (Heywood 2014; Merisotis 2020; Schwab 2016). The pace of technology innovation is altering engineering practice resulting in engineers finding themselves in need to learn about new methods and problem-solving tools that may not have existed during their undergraduate years.

Practicing engineers are approaching interactions with higher education programs from a completely different perspective than traditional undergraduate students. Rather than encountering the problems through the classroom, these engineers come to the learning activity directly motivated by the problems they are facing in the workplace. They seek education programs to inform their own engineering practice which results in these learners having a different set of requirements than traditional engineering student engaging with educational programs (Wlodkowski 2008; Tight 2002). These different requirements must be taken into consideration in the design and implementation of such programs (Caffarella and Daffron 2013; Neidorf 2012).

Instructional Approach

Project-based learning (PBL) is an educational strategy to incorporate practical experiences into the learning process. Rather than learning facts in isolation, application in practice is emphasized (DeGraaff and Kolmos 2007). PBL strategies align well with adult learner characteristics such as self-direction, highly developed experiences, a desire to engage with learning to better cope with real-life tasks and problems, and the focus on performance rather than acquiring knowledge (Knowles 1980). The target population considered here, working engineers, allows for a unique application of PBL strategies. Rather than the instructional team introducing a challenge in the form of a real-world problem or scenario, these learners are coming to the program with their own problems in-hand and are required to apply modeling concepts introduced throughout the course to that problem. Table 1

Table 1. Core PBL Model Characteristics and Application for Working Engineer Learners.

Core Model Characteristics (Barrows 1996)	Project-Based Learning for Working Engineers
Learning is student centered • Student responsibility for learning • Identify needed knowledge • Student personalizes learning	Student-centered learning: aligns with adult learner characteristics
Learning occurs in small groups	Group learning is incorporated through discussion posts, but primarily the work is performed individually
Teachers are facilitators/guides • Metacognitive communication	Iterative feedback provided on course assignments
Problems are the organizing stimulus • Challenge for student	The learners bring their own challenge from their workplace
Problem solving is in context • Problems should simulate real-world	Problems are real-world
New information is gained through self-directed learning • Learning through additional study/research	Learners encouraged to use resources from their own work environments

provides a summary of PBL core model characteristics (Barrows 1996), and their implementation for this specific program addressing PBL for working engineers.

The online delivery of this program takes further advantage of these learners' abilities to integrate their own problems in a learning setting. To facilitate learners using problems from their individual work environments, the learners perform the work individually rather than on teams. This is a notable difference from traditional PBL implementations for this application of project-based learning. Working individually in the course enables these learners to customize their projects to promote integration of workplace problems in the class environment.

The online delivery not only reduces barriers for working engineers such as travel and taking time off work to participate, it enables course designers to take advantage of this delivery method to intentionally change the learning experience for the workforce (Carliner 2019). Online delivery enables the learners to remain in their work environments as they engage with the program. These learners are able to use readily available tools and resources to accomplish the defined learning objectives in the course (Newstetter and Svimicki 2014). Online delivery brings the course to the authentic work environment facilitating connections between application of these methods and the more abstract course concepts which inform the use of these tools. In this case, the program is focused on computational engineering methods resulting in the learning environment and engineering problem environment to overlap in the digital space providing a unique application of project-based learning strategies.

PROGRAM DESCRIPTION

Engineering workflows are moving towards an integrated model-based approach which requires engineers to transition from the traditional design-build-test methodology to an integrated model-analyze-build methodology (DoD 2018). This shift requires engineers to use Computer Aided Engineering (CAE) tools to model and analyze design concepts digitally rather than building expensive physical prototypes which take a long time to procure. Although CAE tools are widely available in the engineering workplace, the shift to a model-analyze-build methodology is hindered by a lack of practicing engineers who are proficient in applying digital tools and methods to solve engineering problems (Magana and Silva Coutinho 2017).

This program focused on the theory and application of Finite Element Analysis (FEA) with examples shown in Figure 1 ("Simulation Innovation and Modeling Center" 2019). This computational technique is a popular Computer Aided Engineering (CAE) method and commonly used in the engineering workplace. FEA is based on the Finite Element Method (FEM) which is a general method for solving partial differential equations. This computational method enables the use of mathematical

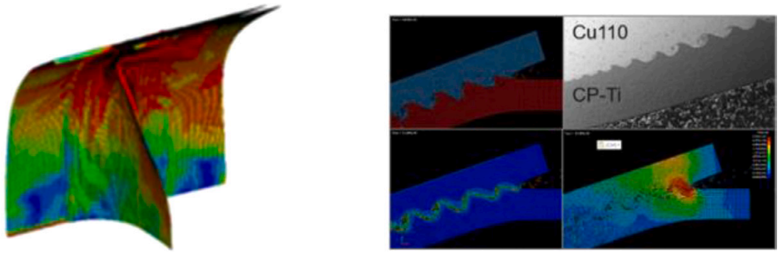

Figure 1. Example of Finite Element Analysis (FEA) models.

modeling of several physical phenomena such as stress and strain in structures, fluid dynamic, and heat transfer (Cooke 2007).

The non-credit Finite Element Principles (FEP) certification program was offered through a university research center using an online, asynchronous delivery and offered courses in specific areas of FEM. Each course was equivalent to 1-credit hour, or 40 hours of work over several weeks. There were four courses offered in the series, and some courses were offered multiple times (Table 2). Completion of three courses was required to earn a stacked certificate (Figure 2).

Table 2. FEP Courses: Registrants and Earned Certificates.

Course	Date Offered	Duration	Registrants	Earned Course Certificates
Foundations of Finite Element Principles (FEP)	Fall 2019	7 weeks	8	7
	Spring 2020	10 weeks	8	7
	Fall 2020	10 weeks	14	13
FEP Linear Dynamic Analysis	Fall 2019	7 weeks	4	2
	Spring 2020	10 weeks	3	2
FEP Heat Conduction	Fall 2020	10 weeks	3	3
FEP Nonlinear Analysis	Spring 2021	10-weeks	5	5
Total	N/A	N/A	45	39

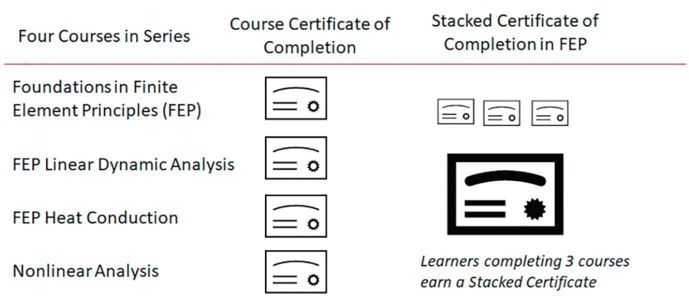

Figure 2. Certificate Program Structure.

The goal was to scope each course so that the weekly time commitment for working professionals was reasonable while also allowing enough time to explore a complex topic with reasonable depth. The course was originally designed for a total of 2 contact hours and 4-6 hours of independent work for a total of 6-8 hours per week required from the learners. The course duration was extended from 7-weeks to 10-weeks based on learner feedback without introducing additional course materials to make the course more manageable for working adults (Nutwell and Stein 2021). The intent was to increase flexibility for the learners in how they interacted with the course. Learners could choose to reduce the weekly time spent on the course or introduce more breaks to better fit their schedules. These learners were incorporating learning into already busy working lives; increasing the course duration was an effort to meet these learners' needs by enabling them to make choices which supported their efforts to fit this activity into their schedules (Martin et al. 2019).

Learners accessed the content and activities throughout the defined timeframe and interacted with the course according to their own needs and schedules. To complete the course, participants were required to use finite element software and were encouraged to use the specific finite element software tools that were available in their own work environments. The university research center was able to provide access to appropriate software tools to learners in the course upon learner request, but no requests were received from any of the learners. All learners used commonly available commercial software packages which were available to them to complete course requirements.

Course Design

The course materials were presented to highlight the connections between theory and practice to contextualize abstract computational engineering concepts using relevant examples and demonstrations (Reisslein, Moreno, and Ozogul 2008). The mathematical complexities were not emphasized to avoid overwhelming the learners; however, sufficient details were provided so that the learners gained awareness and understanding of the concepts as they relate to the use of the Finite Element Method (FEM) to solve complex problems. To emphasize the connection of the theoretical concepts to application, the course was designed with two types of video lectures. A theoretical concept was introduced in a conventional video lecture format. This would be followed by an application video (Figure 3) where the same concept is discussed using a commonly available software tool. The software interface was used only for illustrative purposes with the intention that learners could easily transfer this information to other software interfaces as there are several commercially available software packages offered by various companies ("Abaqus/CAE" 2022; "Ansys Structural Analysis Software" 2022; "Altair Structural Analysis" 2022). The emphasis was not software training but rather connecting the theoretical concepts directly to an application environment.

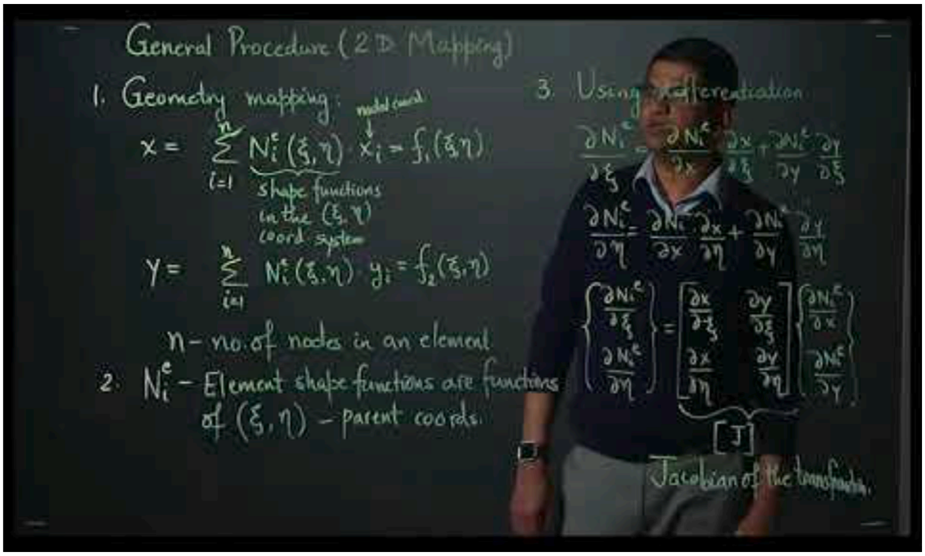

Figure 3. Theoretical video and application video illustrating the concept of element Jacobian and mesh quality. https://www.youtube.com/embed/i30DFRB8lnk?feature=oembed

Presenting the Finite Element Method

Practicing engineers need to learn underlying concepts to make informed choices while using commercially available software interfaces. These interfaces are associated with sophisticated solvers which do not use the direct formulation which is the most convenient approach to introducing the Finite Element Method (FEM). Although this formulation is intuitive and easy for students to learn, it can only be applied to a small class of problems due to numerical limitations. The problems encountered by working professionals are typically complex involving fully three-dimensional problems with several element types, complex boundary conditions and loading scenarios. This program was designed to begin with the direct formulation and introduce basic FEM concepts to relate these concepts directly to modeling application. Once these basic concepts were addressed, the course quickly pivoted to presenting a more complex formulation to support this learning audience.

With any formulation, the Finite Element Method (FEM) solves for displacements {a} using the expression:

$$[K]\,\{a\} = \{F\} \tag{1}$$

where $[K]$ is the stiffness matrix and $\{F\}$ is the force vector. To begin the introduction of a more complex formulation which is the theoretical foundation of commercial solvers available to practicing engineers, the fundamental governing equations of linear elasticity are introduced to relate displacement to strain and strain to stress. At this point in the course, the potential energy formulation is introduced to present the underlying concepts related to modeling decisions that these learners face such as choosing element order, selecting element integration strategies, and mesh quality. These concepts will also provide a theoretical basis for troubleshooting models which do not run or recognize models which may run but produce results that are not physically accurate due to modelling errors on numerical problems. Rather than simply reporting model results, a theoretical understanding of the modeling tool will aid in engineering decision making supporting critical evaluation of model results before basing important engineering decisions on model-generated data (Magana and Silva Coutinho 2017; Hu 2007).

Although considerably more complicated, the advantage of the potential energy approach over the direct approach is that it allows for the treatment of complex problems making it a useful computational method in the engineering workplace. Presenting this approach allows for important application concepts to be discussed including mesh quality, element order, and integration points which cannot be addressed if only presenting the direct method of the finite element method.

In a traditional graduate course, these concepts are presented in an academic setting requiring advanced engineering math such as variational calculus and linear algebra. For this learner audience, rather than approaching the derivation of the stiffness matrix by detailing the mathematical complexities, the course presented the derivation emphasizing the overarching concepts and connected these concepts to modeling decisions (Figure 4). Learners interested in exploring these concepts beyond the requirements of the course are thus better equipped to engage in self-learning activities using the course as a starting point. All learners benefit from an awareness of these theoretical concepts to improve their understanding of the software tools they are using to solve problems in their workplace.

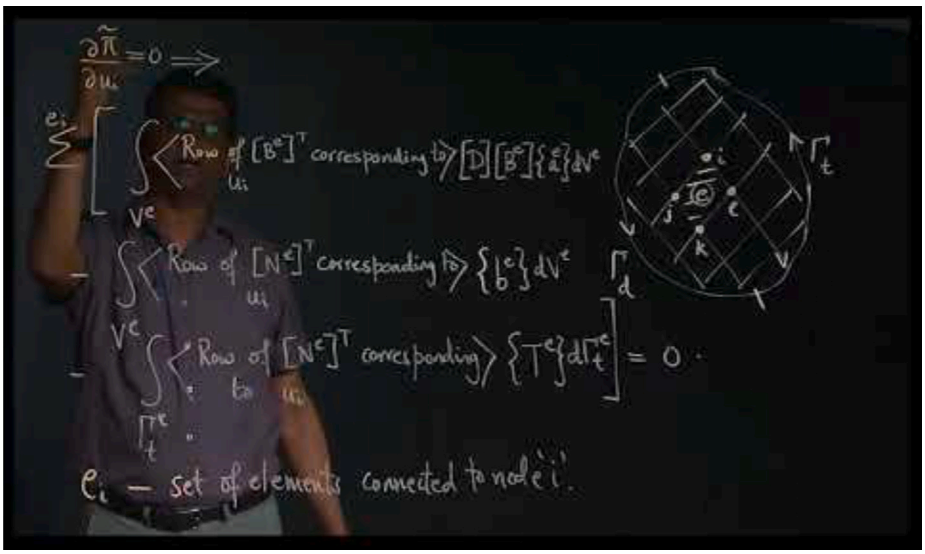

Figure 4. Theoretical lecture connecting minimization of potential energy to the derivation of [K]. ***https://www.youtube.com/embed/KIwNnJh72a4?feature=oembed***

Assignments

Multiple assignment types were included as course requirements such as discussion posts, quizzes, and homework problems. Table 3 presents a description of each assignment, estimated weekly time required to complete, and its role in the course. The primary activity for the learners was to develop a class-long project. The project assignment was designed so that the course could leverage the unique ability of these learners to select problems from their own work or personal environments to connect theoretical concepts to real-world scenarios. This assignment was designed to be scaffolded with multiple submissions throughout the course to tie project activities to concepts presented in each specific course module (Reiser 2018). Instructor feedback was provided to the learners throughout to guide progress and develop conceptual understanding (Hattie and Timperley 2007).

Table 3. Assignment description.

Assignment	Estimated Time per Week	Description
Quizzes	< 0.5 hours	Identify areas of uncertainty with the with the content through multiple choice, self-check quizzes. Multiple attempts allowed.
Discussion Posts	< 0.5 hours	Pose modeling scenarios such as element selection and applying boundary conditions to engage learners in articulating connections between course concepts and application.
Homework Sets	1–2 hours	Reinforce course concepts and give learners opportunity to engage in small coding exercises.
Project Assignment	2–3 hours	Connect course concepts to real-world scenarios through cumulative assignments which require learners to propose, build, and exercise a model, and report results.

The project was broken down into six specific assignments and was structured to guide learners through the model building and analysis process. Figure 5 maps the project topics to the module topics and concepts in the first course in the series, Foundations of Finite Element Principles, and a similar approach was used for other courses in the program. The project activities were structured so that learners were able to apply course concepts to their project assignments promoting the application of concepts to real-world scenario defined by the learners.

The assignments had due dates scheduled throughout the course to encourage learners to adhere to a schedule, but flexibility was allowed. Deadlines were considered soft throughout the course, but learners were required to complete all assignments by the close of the course to earn a course completion certificate. Learners used the deadlines to stay on track in the course, but only 20% of learners who successfully completed the course turned in less than 5% of their assignments late. Roughly 27% of learners submitted more than 50% of assignments past the published due date (Figure 6). Learners used the structure provided in the course to stay on track while also leveraging the flexibility allowed in the course to complete the course requirements and successfully engage with the program. The

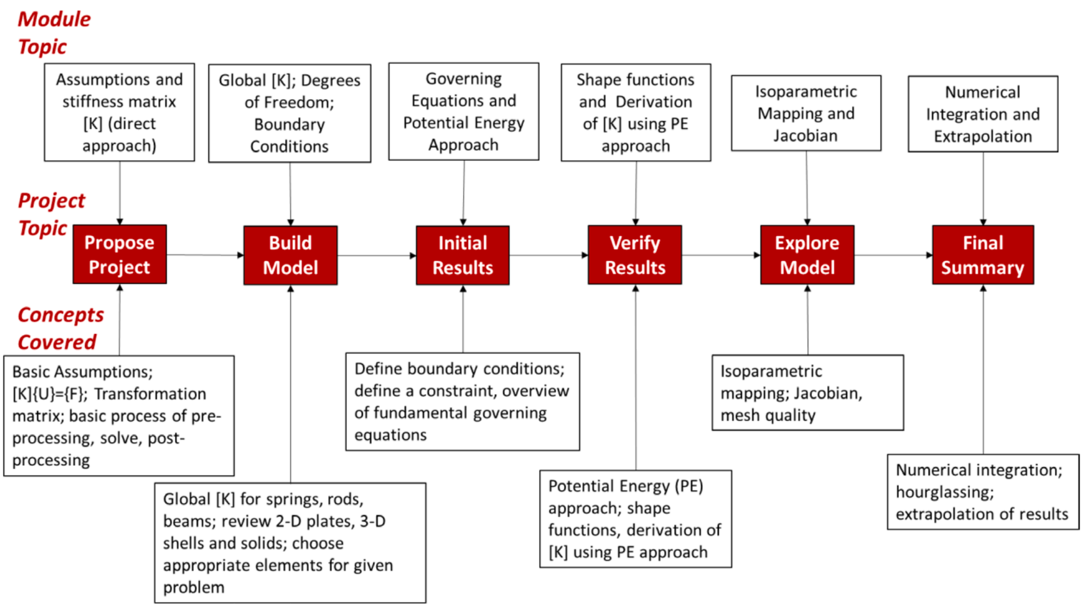

Figure 5. Project Topic Mapped to Module Topic and Course Concepts.

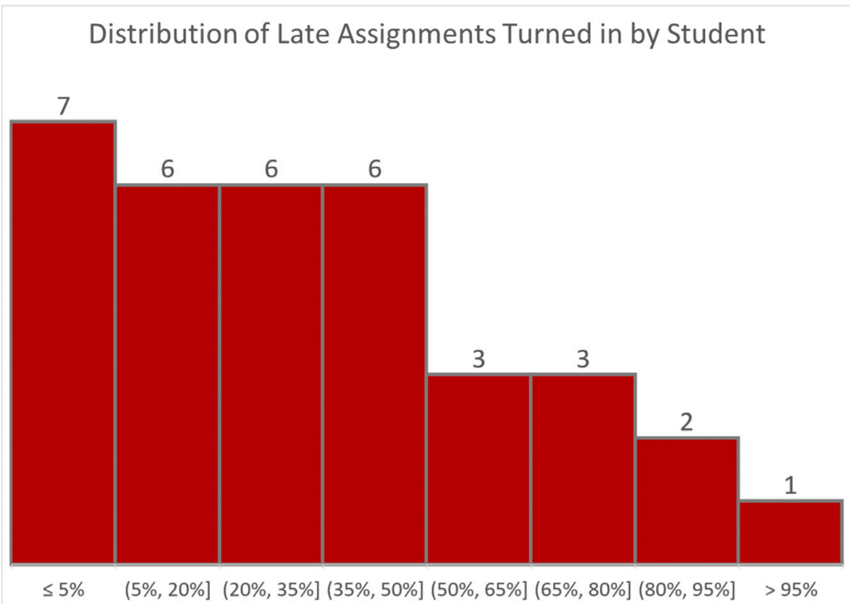

Figure 6. Percentage of late assignments submitted.

need for this flexibility in turning in assignments past the published due date may be an indication that the learners found it difficult to maintain full working schedules while engaging with the course.

SURVEY INSTRUMENT AND RESULTS

An optional course evaluation survey was administered at the end of the course. The survey included fifteen five-point Likert scale multiple choice questions and three free response questions. The survey response rate was 82% of learners earning a course certificate completed a survey.

Program Participation

Course-level certificates of completion were earned for each learner completing a course with 87% of registrants earning certificates of completion for individual courses. A total of three learners earned the stacked certificate by taking three courses in the series, and one learner completed all four courses in the program. Participants were interested in additional courses with 84% of learners either agreeing or strongly agreeing that they were interested in taking additional courses (Figure 7), but only 8% of learners who earned one course certificate went on to earn the stacked program certificate requiring completion of three courses.

One plausible reason for learners not taking additional courses in the program is that the course took too much time and effort even though the courses were designed to be taken while maintaining work commitments. Learners were overall pleased with the amount of effort they put towards the course, but some did indicate that the effort required was more than desired (Figure 8).

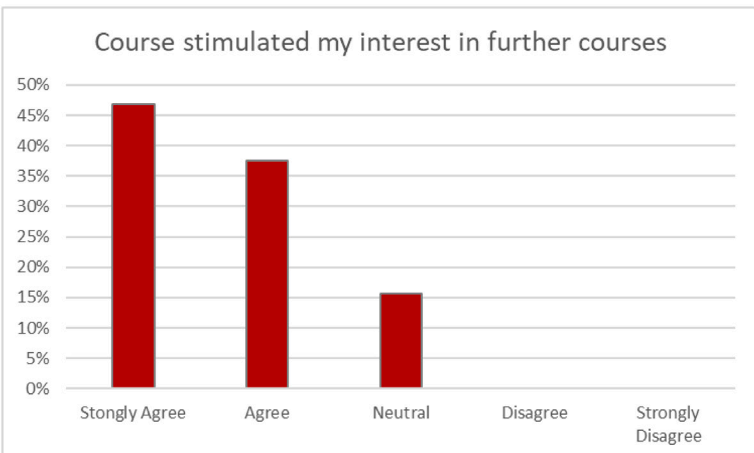

Figure 7. Learner interest in additional courses.

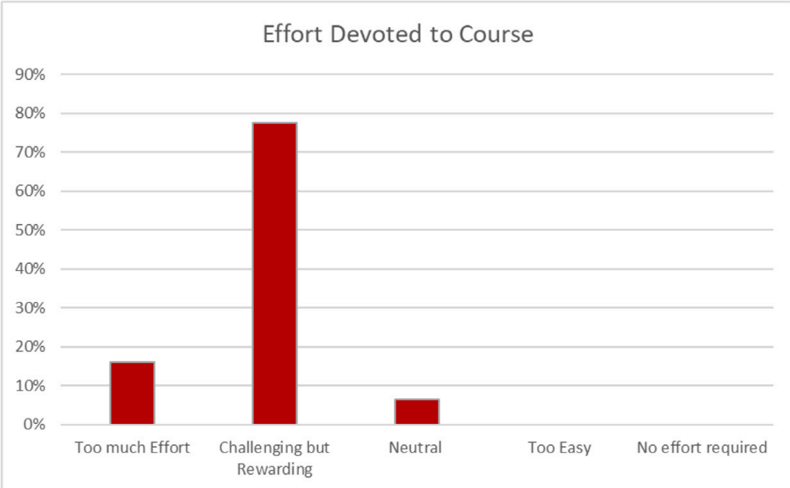

Figure 8. Learner perceptions of required effort.

Learner Understanding of Concepts

The course evaluation results indicate that the course helped develop the learners' understanding of concepts and principles, and that these concepts and skills were relevant to their work. There was agreement that the models, samples, and demonstrations were helpful in the learning process (Figure 9).

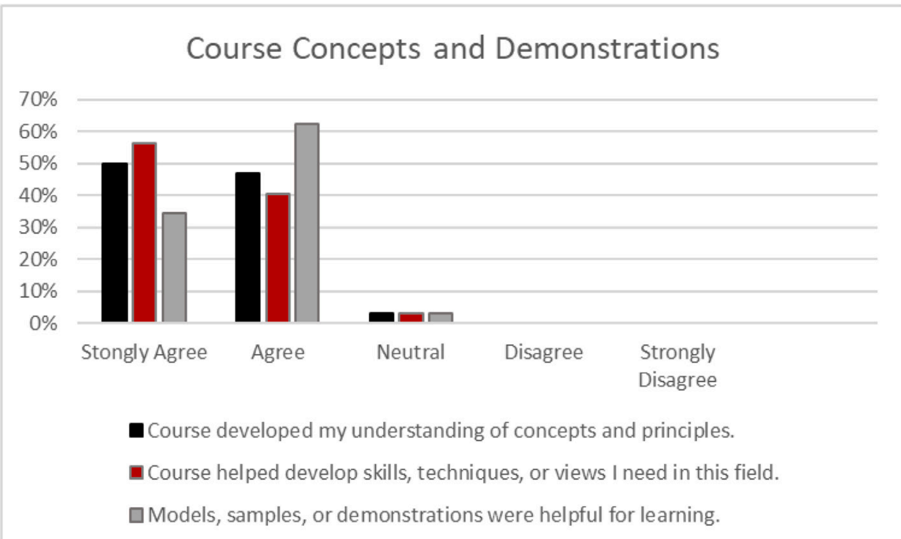

Figure 9. Learner perceptions of course concepts and demonstrations.

The free response question *How do you think the knowledge and skills you acquired in this course will help you in the future?* indicated an overwhelming positive response from the learners who mentioned assorted topics such as greater understanding of topics, model troubleshooting, more engagement with modeling experts, and understanding of model limitations. Only one negative comment was recorded which stated that the theoretical concepts were too involved and there were limited chances to apply the concepts (Table 4).

Table 4. Free response survey answers describing how the course will support learners in the future.

Assignment Type	Example Comments
Modeling Topics	I feel that I can make better informed choices when selecting element types, sizes, and boundary conditions. Previously, I was simply using default values, but now I can think critically about the decisions I make in setting up a model.
Learner Confidence and Engagement with Experts	I've already noticed a difference at work in what I am able to understand when I hear our stress analysts discussing different projects they are currently working on. My hope is to be able to participate in some of those projects soon. We work on a lot of cool things, and engineers with a solid understanding of FEA (*Finite Element Analysis*) are always valuable.
Appreciation of theoretical concepts	Positive: I think a lot of the basic knowledge I learned will help me a great deal. I don't think I'll use the detailed hand calculations or programming I learned as much as the general understanding of what the various options in meshing and simulation actually do, but appreciate learning them.
	Negative: The material that was presented was highly theoretical, probably more so that I will need. However, the opportunities to apply the theory were limited by the project structure. I believe that the class needs to be significantly revised.
Decision Making and model troubleshooting	I now have more knowledge to make appropriate decisions in setting up thermal and coupled thermal analyses. I also have more information on how to troubleshoot my models when the results are incorrect. Knowing the context behind default settings and when to change them will help me set up models correctly.

Assignments

The learners indicated that the assignments were well aligned with the course concepts, appropriate assessment methods were used, and that the assignments promoted interest in the course (Figure 10). A free response question on the survey also provided insight concerning learners' experiences with the various assignment types. When asked what the most productive learning event of the course, several learners identified aspects of the course that were not related to the assignments such as the lectures, worked examples, and specific topics such as element types and integration points, but several learners did identify various assignments in their response, with Table 5 summarizing these responses.

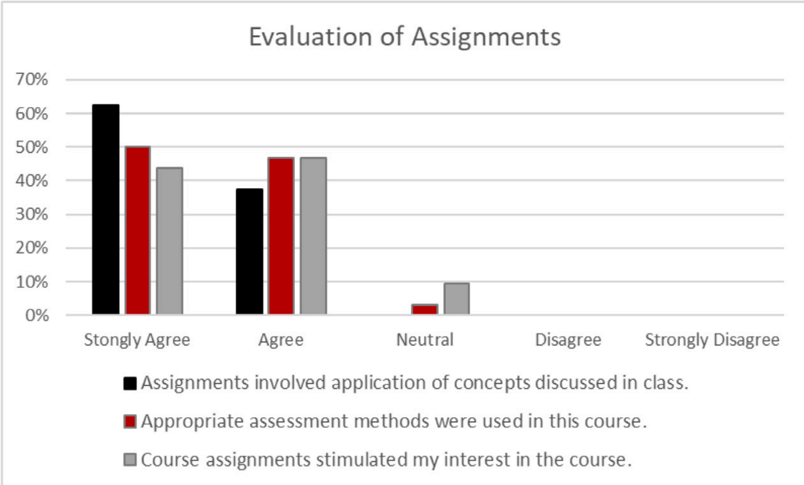

Figure 10. Learner evaluation of assignments.

Table 5. Free response survey answers identifying assignments as a productive learning event in the course.

Assignment Type	Positive Mentions	Negative Mentions	Example Comments
Discussion Posts	0	1	I believe one section that could be higher stressed would be presenting your design/analysis challenges (i.e., projects) in great detail. These can function as great case studies, which I view as highly valuable. I think the discussion post format set up touches on this, however its importance could be stressed higher. I think those posts have high potential in them, they are just not fulfilling it yet.
Quizzes	3	0	The HW and Quiz really helped me understand the concepts being taught
Homework	10	1	Homework problems where you work out the calculations by hand are most productive for me. Scripting is OK but can be distracting to remember syntax.
Project	11	3	Positive: The over-arching project was most productive. The project allowed me to pick aspects that I wanted to learn more about in a high-context scenario. Having it broken down into pieces kept the project manageable. Negative: The project was interesting, but I learned less than I had hoped from going through the application of the topics. Perhaps would have been easier and less frustrating to work through a pre-set multi-week problem, rather than trying to set the problem statement and analysis parameters by myself.

The comments which mention the project negatively focused on the time required to build and analyze the project and the unstructured design of the project assignment. Positive comments focused on the learners able to select their projects from their own work environments. This was possible because the course design was fundamentally a project-based learning strategy but had learners working individually rather than on teams. Quizzes and discussion posts were smaller assignments in the course and not mentioned as often as homework assignments and the project assignment.

DISCUSSION AND CONCLUSIONS

Project-based learning (PBL) methods were well suited for this learner audience as PBL strategies are well-aligned with adult learner characteristics. Learner feedback indicated that the course content provided technical depth, and the focus on application contextualized these concepts so that the learners could directly apply these concepts to model application, decision making, critical evaluation of results, and model troubleshooting. Although the feedback from the learners was overall positive, very few students continued with the program and took only one course. The reasons for this are not clear from this study, but indirect evidence, such as students consistently turning in assignments late, indicate that these learners did struggle with the time and effort required to complete the course. This was addressed in the initial design of the program limiting the amount of time required weekly of the learners to 6-8 hours, and further addressed by extending the course length without adding material, but this remains a struggle point.

Another issue which may have influenced these learners deciding to leave the program after one course is the learners' preconceptions around professional development. Traditional delivery of professional development programming is an isolated workshop-style offering. These short courses are typically conducted over a short period such as a couple of days. Traditional professional development programs are often delivered at a conference or other external setting using tools provided by the program rather than using resources available in the work environment of the learners (Wells 2007). Although this program provides an alternative design which uses an extended delivery over multiple weeks, the ability to interact with the course while maintaining work commitments, and the incorporation of tools familiar to the learners, the learners were accustomed to more traditional delivery of professional development programs. Once learners registered for a class, there was a high success rate of students earning course level certificates (87%) and students responded positively to the course. However, over 90% of learners left the program after engaging with only one course despite their success and positive reactions to the course. Along with deep experiences, adult learners also come to learning programs with preconceptions about learning (Knowles 1980; Wlodkowski 2008). These learners may be applying more traditional perceptions of professional development programs to this experience and choose to limit their participation to one course despite the course design enabling learners to engage with the program with multiple courses.

Closing the gap between the classroom and the work environment for working engineers involves bringing the course content to practicing engineers. This contrasts with traditional applications of PBL strategies which aim to bring context to students. In both cases, the problem initiates the learning process, and the course supports the problem solving process (Bertel et al. 2021); however, integrating conceptual understanding with application must consider the different needs of this distinct learner audience in the course design process.

Practicing engineers must continue to learn and apply modern technologies to meet the demands of the modern engineering workplace. Lifelong learning, often discussed in engineering education literature (De Graaff and Ravesteijn 2001; Litzinger, Wise, and Ha Lee 2005; NAE 2009; Rugarcia et al. 2000), does not distinguish between informal and more formal activities. Incidental learning on the job is critical to the growth and development of practicing engineers, but when adopting new tools and methods such as Computer Aided Engineering (CAE), engineers must also engage with more structured education programs. More experienced engineers are unfamiliar with new methods and are not able to mentor younger engineers in unfamiliar tools and methods, and the complex and technical nature of computational engineering requires more formal presentations of the underlying theories to support their use and application in the engineering workplace.

Working engineers see the need for continuing education addressing new methods and problem-solving approaches that are changing the engineering workplace. Higher education institutions are uniquely positioned to partner with the engineering workforce to engage learners on their terms to provide unique offering for this audience. Combing online delivery with project-based learning strategies provides not only flexibility to the course design, but also enables learners to engage with courses while honoring their extensive experiences and existing engineering knowledge base. This nontraditional learner audience provides opportunities for course designers to catalyze working engineers' unique capabilities in developing courses and programs using unique and innovative instructional approaches.

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