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Integrating Industry-Based Case Studies into Graduate Transportation Engineering Education

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Innovations in Graduate Education (IGE): Integrating Industry-Based Case Studies into Graduate Transportation Engineering Education

Background

In today's graduate career landscape, it is important that graduate students are prepared for a variety of career paths. This paper is a continuation of an NSF-funded Innovations in Graduate Education (IGE) project, which seeks to tailor a graduate transportation engineering program for industry and/or government careers. This program has been structured around the cognitive apprenticeship framework, due to its ability to teach novices the expert problem-solving process [1]. To enhance the industry-relevant competencies of transportation graduate engineering students this program has partnered with industry and government professionals to build out industry-based case studies that can expose transportation graduate students to the complexities of real-world problems that they would face in a non-academic setting. Case studies and applied problems have been integrated in both graduate coursework as well as key graduation exams such as the qualifier.

Case studies can be used to introduce graduate students to non-academic problems, improve their real-world problem-solving skills, and enhance their technical competencies by targeting their knowledge, skills, and abilities, or KSA's. Case studies require students to rework open ended problems in a way that reinforces their technical abilities and places technical skills in the context of real-world engineering practices [2]. They are also used as a method to understand the relationships between theoretical constructs, practical applications, and contextual concepts [2], [3], [4]. Case-based learning has been a well-documented method in engineering education to improve critical thinking and problem solving skills [5], [6], [7], [8]. Others have reported that case-based learning results in higher level learning according to Bloom's taxonomy, such as analyzing, evaluating, and creating [8], [9], [10]. Finally, case studies improve engineering students' ability to transfer classroom knowledge to complex, real-world problems and professional contexts. The overall goal of case-based learning is for students to apply strategies they have learned in class to novel, real-world problems [5]. Students who experience case-based learning in the classroom are able to make better connections between course material and real-world applications [9].

Case studies also fulfill multiple principles within the cognitive apprenticeship framework: *domain knowledge* from the Content domain, *articulation* from the Methods domain, and *culture of expert practice, situated learning,* and *exploiting cooperation* from the Sociology domain. The Content domain groups the different types of knowledge required for expertise, and *domain knowledge* specifically refers to the conceptual and factual knowledge identified with a particular subject matter [1]. This principle provides the baseline of knowledge, but does not provide information on problem solving, which is where case-studies can be of use since they provide the opportunity to apply *domain knowledge* learned from courses to real world problems [5]. The Methods domain describes how all other principles of cognitive apprenticeship are successfully integrated into the classroom, and it includes *articulation.* This occurs whenever students communicate or express their knowledge, reasoning, or problem-solving processes. These sorts of processes are linked to higher learning levels of Bloom's taxonomy, which case-studies have shown to be able to improve [8], [9], [10]. Finally, the Sociology domain provides various social environments for students to learn in, such as *situated learning, culture of expert practice,* and *exploiting cooperation.* In *situated learning*, students carry out tasks and solve problems in environments that reflect areas in which they will apply that knowledge in the future. *Culture of expert practice* encourages students to "think like experts" by creating an environment where students engage in the skills involved in expertise. Case studies develop a foundation for *situated learning* and expose students to a *culture of expert practice* by providing them with an opportunity to apply their technical skills in the context of real-world engineering problems [2]. *Exploiting cooperation* refers to students completing the same task and comparing their processes, which allows them to be more direct in their strengths and weaknesses [1]. In this study specifically, students complete the case study in teams and are each required to provide an alternative solution, providing them with the opportunity to compare their problem-solving processes.

This paper introduces a rubric for implementing case studies based on the cognitive apprenticeship elements it is able to support. This rubric was used to evaluate case studies that have been implemented in the program so far including in a Bridge Design course, and within graduate students' qualifier exams.

Methods

The following sections will describe the methods used to develop the rubric to evaluate the case studies based on cognitive apprenticeship principles and provide a brief description of the case studies that were evaluated.

Rubric Development

To create the initial draft of the rubric, Google NotebookLM was utilized as it will only work from the sources uploaded to the AI [11]. The sources uploaded to NotebookLM were a journal article describing each principle of the cognitive apprenticeship framework [12], a section of the original IGE project description that details how case studies would be used to improve technical competency, and the case study project description from the bridge design course. The AI was then prompted to create a rubric with a 0-2 scale (0 being unfulfilled and 2 being completely fulfilled) for how well case studies in a graduate level transportation engineering course could meet *domain knowledge, articulation, culture of expert practice, situated learning,* and *exploiting cooperation*. This rubric was then reviewed by a member of the research team who specializes in the cognitive apprenticeship framework to refine areas and ensure each principle was accurately reflected. Changes were made to make the case studies the focus of the rubric, make the categories broader, and adjust the levels and principles to accurately reflect the definitions of each principle. The final rubric is presented in Table 1.

Table 1 Rubric to assess case studies based on principles from cognitive apprenticeship framework *[1]*.

Principle	0: Not Addressed	1: Partially Integrated	2: Fully Integrated
Domain Knowledge	Case study focuses solely on solving problems through procedures or algorithms learned in class.	Case study incorporates relevant concepts and procedures, application is limited or loosely connected to professional standards.	Case study requires robust application of **concepts, facts, and procedures** (e.g., AASHTO specifications, LEAP software) with **strategic knowledge** to solve complex, real-life design tasks.
Articulation	Case study requires submittal of final results (e.g., bill of quantities) without reasoning, assumptions, or decision process.	Case study requires students to describe *what* they did but does not require a verbalization of their knowledge, reasoning, or problem-solving process**.**	Students must **verbalize or communicate their knowledge and reasoning** through "Head-to-Head" presentations, peer critiques, or "abstracted replays" of their problem-solving steps.
Situated Learning	Case study is abstract, decontextualized, and lacks real-world relevance.	Case study uses realistic data but is performed in segregated environments where connection between contexts and future use is limited	Students solve **authentic problems** in a context reflecting future professional use where decisions are inseparable from environmental, economic, and stakeholder considerations.

Principle	0: Not Addressed	1: Partially Integrated	2: Fully Integrated
Culture of Expert Practice	Case study is focused on academic exercises and is disconnected from professional application and practices.	Case study encourages students to use industry tools (e.g., PGSuper, Simon LRFD) but does not reflect authentic constraints, standards, or expectations.	Case study embeds students in a **community of practice**, solving industry-related problems while reflecting real agency contexts such as managing trade-offs and meeting professional standards.
Exploiting Cooperation	Case study is designed for students to work entirely independently with no meaningful collaboration.	Case study is designed for students to divide labor into isolated sub-tasks rather than sharing reasoning and synthesis. Additionally, students may compare results instead of problem-solving processes.	Case study is designed to engage students in **cooperative problem solving** through joint analysis, integrating perspectives, and co-constructing solutions.

Case Studies

There were two case studies evaluated in this paper. The first was a case study for a course project in a Bridge Engineering design course where students were required to design a number of design alternatives (equal to the number of team members) of steel or concrete bridges. Students were encouraged to design their bridges in software such as LEAP Bridge, Simon LRFD or PGSuper, and were required to follow AASHTO Bridge Design Specifications and steel bridge manuals. At the end of the project, teams would submit a drawing of each bridge design, a bill of quantities for each superstructure, and evaluate each bridge based on their economic impact, constructability, and environment-based emissions. Finally, teams would present the key points of their bridge designs in a head-to-head format with other teams.

The second case study was completed during graduate students' qualifier exams, which took place 12-18 months into their program. Contents of each qualifying exam vary per student, but typically contain an engineering design problem, and an open-ended case study problem written by the non-academic/industry member that serves on the student's research committee. These questions vary across exams, and may ask students to assess sustainability and performance of materials in real-world projects, investigate a data set to determine what they believe could be a contributory cause to a problem, or place students in the role of an engineer to evaluate materials or fulfill a customer's design. Students are typically provided with a data set to begin their analysis, but are encouraged to use additional information from databases, publications, and resources.

Results & Discussion

This section provides evaluations for each case study and offers suggestions on how to strengthen any noted areas of weakness.

Bridge Design Case Study

The Bridge Design case study was the first to be evaluated using the rubric. Starting with *domain knowledge*, it was determined that this project fully integrated (2) this principle into the case study. Students were required to apply technical knowledge they had gained in class to design steel and concrete bridge superstructures, use software such as LEAP Bridge, Simon LRFD, and PGSuper to design the bridge deck and girders, and check the bridge loading and analysis using manual calculations. Furthermore, they were asked to follow their steel bridge manuals and AASHTA Bridge Design Specifications from varying states when designing their bridges, thus fulfilling the requirement to use concepts, facts, and procedures in combination with strategic knowledge to solve a real-life design task. When ranking *articulation*, the project partially integrated this principle (1) mainly due to the required submissions from students. Students were asked to turn in a drawing for each bridge design, a bill of quantities for the bridge superstructure, and an evaluation of the bridge based on its economic impact, constructability, and environmental emissions. While some of these evaluations go beyond a simple sheet of calculations, none of these submissions probe at the students' knowledge, reasoning, or problem-solving process. Additionally, students were asked to develop a presentation summarizing the key points of their bridge designs that were presented in a head-to-head format. While this has the potential to create *articulation*, it was not clear from the project description or student submissions if students were asked to upsell their designs or justify their design decisions. To fully integrate *articulation* into this project, submissions could include periodic reflections from students that ask them to describe their problem-solving process, or students could be asked to support their design decisions during the presentations.

This project was able to fully integrate (2) *culture of expert practice,* but only partially integrate (1) *situated learning*. This case study used realistic data to solve an authentic, industry-related problem of bridge design, which some students may be required to do in their future. Additionally, it required students to come up with multiple design solutions, use industry relevant software, follow authentic procedures and specifications, and evaluate their bridges based on real stakeholder needs. For these reasons, it fulfilled the requirements needed to fully integrate *culture of expert practice*. However, design decisions for the bridges were able to be made separately from environmental, economic, and feasibility constraints, which were considered after the bridge designs were complete. Furthermore, the connection between this project and future uses is limited – are students aware of how often they may be faced with these design decisions or calculations? What are the most salient aspects of this project that would relate to their future careers? This project could improve *situated learning* by improving immersion in the project, for example, students could take on the role of a project engineer with a budget, timeline, and emissions standards. Finally, this project partially integrated (1) *exploiting cooperation*. While it was recommended that all team members work on all bridge designs together, the number of alternatives equal to the number of team members may have encouraged students to break off and work on their own designs. In the student submission that was received, it appeared that this was the case, as only 3 out of 4 design alternatives were complete. By incorporating guidelines for working together or implementing deliverables that would have to be accomplished by the team, this could be mitigated.

Qualifier Exams

In total, four qualifier exam questions were evaluated for cognitive apprenticeship using the rubric. It was determined that each qualifier exam question fully integrated (2) *domain knowledge* when asking case-based questions. These questions typically required a strong application of concepts, facts, and procedures students had learned throughout their duration of the program by asking students to complete complex tasks such as computing Area Under Pavement Profile (AUPP), estimating tensile strength, and conducting analysis using specific data sets. Students are required to use strategic knowledge to solve these problems by using outside resources that may have not been provided to them at the beginning of the exam. Some exams were able to fully integrate (2) *articulation* in their case-based questions, while others fell short. For example, one of the exam questions asks "*As a consulting engineer, how would you use these data to estimate the fatigue life od the asphalt pavement?"* This question requires the student to not only refer to the given data and potentially dig deeper into outside resources but then use the data to support their estimation thus articulating their problem-solving skills. However, other questions did not reach this level of articulation, asking students to compare properties of materials, or determine if the given asphalt met stiffness and structural requirements.

Similarly, some qualifier exam questions were better at integrating *situated learning* than others, but overall, these questions were able to partially integrate (1) this principle. All these questions used realistic data to solve authentic problems that students may face in the future, however, many did not involve consideration of stakeholder conditions, and could be solved in isolation from any contextual considerations. Additionally, these are still exam questions which dictate how students will progress with their program, which may make it difficult for students to feel immersed [13]. The qualifier exam questions partially integrated (1) *culture of expert practice* into the case-based questions. Some of these questions encouraged students to "think like experts" by taking on the role of a consulting engineer or required the use of professional tools or data to solve industry-related problems. Other questions were able to reflect authentic constraints and standards a transportation engineer may face in their career, such as flushing and bleeding. However, these questions failed to make students consider trade-offs when solving problems or meet any professional standards. One question asked the student to assess potential benefits and challenges considering sustainability, cost-effectiveness, and performance; however, this compare and contrast approach does not fully reflect the trade-offs an engineer may face when making design decisions. Lastly, *exploiting cooperation* was not applicable for the qualifier exams, as students were required to work alone.

Conclusions & Future Work

In this paper, a Bridge Design project and qualifier exam questions were evaluated using a rubric designed to evaluate principles of cognitive apprenticeship that can be fulfilled using case studies within graduate programs. Both pilot projects were able to fully integrate *domain knowledge*, the qualifier exam questions were able to fully integrate *articulation,* and the Bridge Design project was able to fully integrate *culture of expert practice*. However, both the bridge design project and qualifier exam questions only partially integrated *situated learning*. These questions excelled at having students use realistic data to solve authentic data, but fell short when integrating environmental, economic, and stakeholder considerations into the design or decision-making process. Often, these were captured in evaluations completed after the problem had been solved, segregating these real-world contexts from the original problem. Furthermore, the Bridge Design project was unable to fully integrate *exploiting cooperation*, as the number of alternatives needed may have encouraged students to divide the work and create their own individual designs. These shortcomings may be amended if the projects were to include a role-playing aspect where students are on a project design team, and must take into consideration their budget, timeline, and local emission guidelines. Furthermore, requesting deliverables from the students that would require them to work together (e.g. brainstorming session, internal evaluation of designs, etc.) may increase cooperative problem solving as well.

Moving forward, case studies will be designed and implemented into five major content areas within transportation engineering: 1) Construction Materials, Pavements, & Asset Management, 2) Transportation Safety & Intelligent Transportation Systems, 3) Concrete Materials, 4) Bridges, and 5) Geotechnical Engineering. Case studies will be co-constructed between faculty and industry members and implemented into graduate courses by faculty members based on their level of expertise within the case study topic. The rubric will be used to provide formative feedback to instructors as they develop case studies and to dissertation committee members providing practice problems for the qualifier exam. The rubric can also be adapted to assess student work, particularly for the in-class case studies and projects.

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