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Applying Problem-Based Learning in a Building Information Modeling Course*

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Building Information Modeling (BIM) provides many theoretical benefits to construction teams, but practical challenges and issues during implementation hinder companies' ability to realize its full value. Educational research suggests that problem-based learning may support students learning the necessary skills required to resolve the common issues in BIM-based construction projects. While the literature indicates value to problem-based learning for BIM education, the process for creating problem-based learning modules for BIM is less clear, which forces educators to make their best guess at how to create effective learning modules. In order to provide a consistent methodology that will enable educators to create effective BIM-related problem-based learning modules, this study proposes a structured process for developing learning modules. The proposed learning module development process involves several tasks aimed at strategically developing and validating problem statements to ensure that they represent the types of problems students are likely to face in their careers. Additionally, the process of developing an implementation strategy involves tasks intended to ensure that students are motivated to complete the learning module and instructors are prepared to assess the success of their students. To test the feasibility of this process, the authors created an example BIM learning modules related to common people- and process-related BIM problems. To validate the applicability of these modules and implementation strategy, the developed modules were presented to industry experts who confirmed that they were representative of the types of problems they faced and skills they believe are necessary to resolve the defined problems. This paper contributes to the engineering education body of knowledge by presenting a re-useable methodology for developing problem-based learning modules and creating a lesson plan for implementing the developed modules for BIM education.

Keywords: Building Information Modeling (BIM); problem-based learning; industry practitioners

1. Introduction

Building Information Modeling (BIM) has been defined as the development of digital models that include both physical and functional attributes [1]. These models can integrate information in a manner that can impact all lifecycle phases of building projects [2]. Effectively leveraging BIM in construction projects can provide major long-term benefits for procurement, construction, pre-fabrication and facility management [3]. The recognition of these benefits has spurred the adoption of BIM in architecture, engineering, and construction (AEC) projects.

While BIM has many potential benefits, issues on projects, such as technical and managerial difficulties [4], and the presence of unaligned stakeholders [5], can hinder the realization of those benefits [6]. Furthermore, specific issues such as coordination between project activities and change resistance among individuals can inhibit the success of implementing BIM in construction projects [7]. Although BIM involves using technology, more than four-fifths of the recurring issues in BIM-based construction projects are related to the people and processes [8]. Specifically, the most common people- and process-related BIM issues were found to include: transfers of information (ex. not updated with the latest information); changes (ex. sudden modifications in previously agreed details); individual personalities (ex. field personnel ignoring recommendations from modeling team); and human error (ex. misclicks in the model) [8]. This illustrates that, while BIM is directly related to emerging technologies, the most common skill required to avoid critical BIM failures, relates to people and processes.

Prior research has identified several of the most critical skills for individuals to have to address common people- and process-related BIM problems. These identified skills include analytical and problem-solving, communication, initiative, planning and organizational, and teamwork skills [9]. While these skills are necessary for BIM-specific contexts, educational researchers in other, non-BIM, domains have demonstrated the potential of problem-based learning for enhancing some of the same skills [10–12]. Some educational researchers in

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the BIM domain have also published works that illustrate the potential for problem-based learning to support BIM education [13, 14]. While there is evidence that problem-based learning can support BIM education and the skills necessary for resolving critical BIM issues, a structured process for developing effective BIM-related problem-based learning modules does not currently exist. This lack of a structured methodology can lead to potentially ineffective educational strategies that fail to realize the theoretical benefits suggested by prior literature.

Therefore, this paper provides a structured process for developing a problem-based learning module and also for defining an implementation strategy for the module. It addresses the following research questions:

- How should a problem statement be created for a BIM-related problem-based learning module?
- How should BIM educators develop implementation strategies for the developed problem-based learning modules?

The authors address these two questions by defining methodological steps to create learning modules and also by defining steps for educators to create appropriate implementation strategies. In order to test the effectiveness of the proposed process, the authors created several learning modules related to the common people- and process-related BIM problems that have been observed in the AEC industries. To further validate the quality of the developed modules, industry practitioners who directly engage with BIM projects were interviewed to verify that the content in the modules aligned with the problems and needs that they have observed in practice. The contribution of this work is in providing a structured methodology that other educational researchers may use to develop new BIM-related problem-based learning modules. As the problems observed on BIM projects and necessary skills required in BIM professionals evolve, this methodology will enable educational researchers to update learning modules to create learning experiences that effectively target the skills students will need for career success.

2. Background

2.1 Teaching non-technological skills of BIM

Several studies have explored people- and process-related issues related to BIM [8, 15, 16]. Despite the needs of the industry for individuals with these skills, educators have traditionally focused on developing BIM curricula that focus on the skills for using the technology [17–19]. While the technological skills associated with BIM are undoubtedly important, these prior studies indicate that there is a need for educators to prepare students with better people- and process-related skills required for effective BIM implementation in practice. Furthermore, prior research suggests that situating learning content in a realistic problem context that mimics the types of challenges students may face in their careers can yield greater performance benefits among students [20, 21]. The recognition of this opportunity for improvement has led some educational researchers to explore different, and potentially better, educational strategies for teaching BIM, including problem-based learning.

2.2 Problem-based learning in BIM education

Prior works are already experimenting with different approaches to prepare students with the skills required for BIM [22–24]. Specifically, problem-based learning has been used in BIM education to introduce students to numerous technologies and processes, and to integrate project scope, team collaboration, and project planning in a BIM course [14]. Problem-based learning has also been used to help students learn about implementing BIM throughout the lifecycle of a building project [13]. These studies provide insights into the beneficial impacts of implementing problem-based learning in BIM courses. However, their focus was on the implementation and assessment of these educational modules, not on the development of them. While this provides evidence to justify the use of problem-based learning, it also highlights a need for a structured methodology that will enable educators to develop relevant BIM problem-based learning modules and also implementation strategies for those modules that can effectively prepare students for their careers.

3. Methodology

The authors of this work propose methodological steps to (i) create the 'problems' for BIM-related problem-based learning modules; and (ii) develop lesson plans for implementing those modules in BIM courses. After defining the proposed methodology, the authors test the feasibility of their method through the creation of BIM-related problem-based learning modules and validate the applicability of their modules and assessment strategies through expert interviews. The following subsections detail each of these steps.

3.1 Creating the problem (Phase 1)

The actual 'problems' in problem-based learning are critical to successfully implementing this mode of education [25]. The authors aimed to adhere to previously published guidelines, where possible, but often had to tailor this content to relate to a BIM

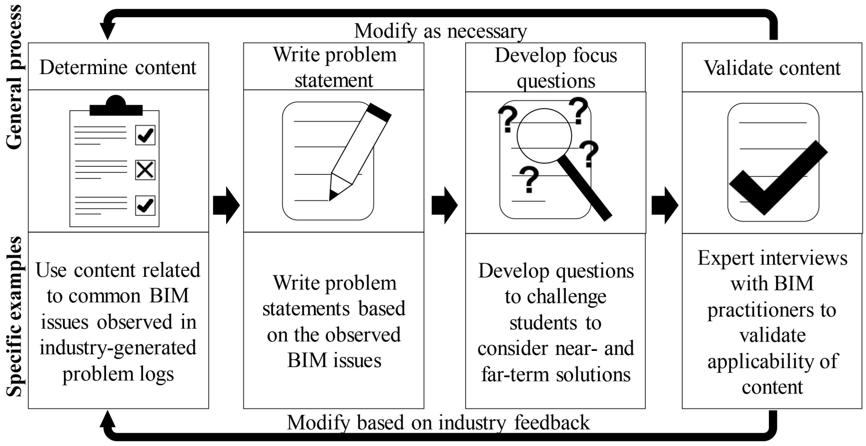

Fig. 1. Proposed methodology for generating BIM-related problem-based learning modules and specific strategies used to illustrate the application of this methodology.

education context. Fig. 1 shows the general steps included in this process, as well as the specific types of tasks that the authors performed to test their methodology, which are discussed in the subsequent sections.

3.1.1 Determining content

In order for educators to develop effective problem-based learning modules, they must first determine the content that will be incorporated into the learning experience. In some fields of education, targeted content may be determined by referencing a program's curriculum or national standards [26]. However, for emerging educational needs related to BIM, established standards may not adequately guide researchers in developing content that supports the current needs of the industry. Therefore, the authors propose referring to BIM-related problems that have been documented, or otherwise observed, in industry.

To test this strategy, the authors used a list of previously-identified issues that were commonly observed in BIM-based construction projects (i.e., changes, human error, individual personalities, and transfers of information) [8]. This prior work leveraged actual project-related problem logs to identify the most common issues currently observed in BIM projects. In addition to providing practical validity to the learning content, this approach also helped to create content that was timely to the current industry, which may increase students' motivation [27, 28].

Future researchers may choose to use a similar set of published literature to guide their problem-based module development, or they may elect to define their own problem content. Either way, the authors suggest grounding all problem content in a practical industry context. This can help to ensure that the eventual problem-based learning content offers practical validity.

3.1.2 Writing problem statements

After identifying the targeted learning content for problem development, the actual problem statements to be provided to the students need to be created. According to Delisle [26], a problem statement should be: developmentally appropriate; curriculum-based: grounded in students' experience; and ill-structured. The authors aimed to leverage these recommendations by ensuring that problem statements: considered the students' intellectual development and social-emotional needs (i.e., developmentally appropriate); promoted the acquisition of appropriate skills and content knowledge grounded in the curriculum (i.e., curriculum-based); related to the students' prior experiences and the course topics (i.e., grounded to students' experience); and led students to multiple possible solutions (i.e., ill-structured). These considerations helped to ensure that the problem statements created would not only be relevant to the students who address them, but also that they would lead to learning that is relevant to the course. In order to illustrate how these considerations may be applied, the process for developing the BIM-based problem statements that were created to validate the overarching methodology is presented in the subsequent paragraphs, according to the considerations needed for effective problem statements.

In order to target content that was developmentally appropriate for the students, the authors needed to present problem statements that would be understood by the students. The targeted students had prior exposure to BIM software applications earlier in the semester in the targeted course, and also through an introductory BIM course that they completed in a prerequisite course. This meant that students possessed at least a basic level of conceptual knowledge related to the technological tools that related to the problem content, making the problems developmentally appropriate for the students.

To make problem statements that were curriculum-based, the authors targeted a BIM course that involved some point-and-click types of learning, but also included managerial topics related to BIM planning. For example, the students in the targeted course were required to develop in-depth BIM execution plans aimed at addressing many of the managerial issues that could arise on BIM projects. Because of this direct tie of the course's core learning content and the targeted problem content, the material included in the problem statements was believed to be sufficiently curriculum-based.

Creating problem statements that relate to students' experience can potentially be challenging—especially if they have not had any industry experience. Fortunately, nearly all students in the senior-level course targeted had completed two summer internships (see Fig. 2 for the relative location of the problem-based learning module in the authors' program). While these internships are unlikely to have exposed students to all possible BIM problems, it is likely that they encountered the types of people- and process-related challenges that were targeted in the problem content in other, non-BIM, contexts during their internships. Therefore, the students would likely be able to recall whatever experiences they did have when considering the contexts of the BIM problems that may be new to them. The authors felt that this would help to ground problem statements within the students' experience.

Finally, problem statements were reviewed to ensure that there was not a single "obvious" answer that would lead to convergent thinking among students. To achieve this aim, the authors added details to problem statements that would prevent students from making assumptions that would render the problem too simplistic. Furthermore, they drafted problem statements that introduced scenarios that would prove to be immediately problematic on an actual project, meaning there was no way of avoiding at least inconveniences among BIM teams. These strategies helped to ensure that the problems were sufficiently ill-structured to challenge students to consider what strategies might be best to address the problems.

For future educators developing problem statements using this methodology, they may need to consider how they present the problem statements in an educational context. Part of the challenge of presenting industry-based problems is that students, who may have little or no industry experience, must understand them. If students do not have sufficient industry experience, future educators may consider defining problem statements that are related to industry problems, but include situations that students have directly experienced through course projects or other similar academic experiences.

3.1.3 Developing focus questions

After defining the problem statements for the learning modules, focus questions were developed for the module. Focus questions help to guide the direction of students' thinking on their task after they become interested in the problem [26]. For this work, it was of particular interest to focus the students' attention on resolving the people- and process-related challenges that were part of the problem presented to them.

To illustrate how relevant focus questions can be developed, the authors defined two focus questions for the students to challenge them to think about how they would resolve the problem in the near- and long-term. Students were required to generate a list of strategies to resolve the provided issue in the immediate short-term (i.e., What would you do to address this BIM problem and its impacts today?). Subsequently, students were required to justify their chosen approach. They were also required to create a list of strategies to avoid the provided problem from recurring in the future and, again, justify their chosen strategy.

In some instances, the focus questions were developed to relate to each problem, specifically. This was especially important for problem statements that could potentially be considered to be too ill-structured to the point where students might deviate from the intended course content to resolve the issue. For example, in some problems, students may want to simply "fire a subcontractor," but this type of response has implications that go beyond the scope of the course. Therefore, by forcing students to think about how they would immediately solve a problem, this type of response is less enticing

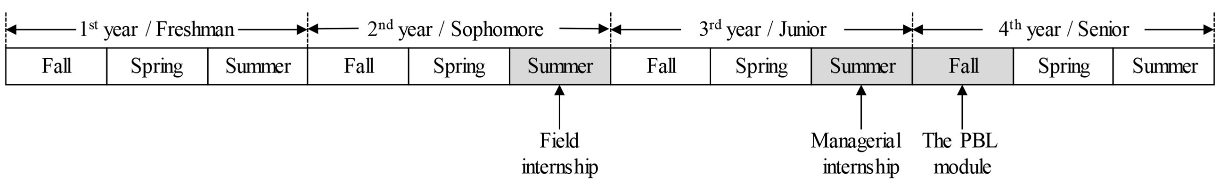

Fig. 2. The relative location of the problem-based learning module in the authors' program.

because it does not immediately resolve whatever BIM deliverable they believe the subcontractor failed to provide.

3.1.4 Validating the drafted problems

After developing problems and focus questions that are believed to address the aims suggested in this paper, the authors suggest a validation activity to ensure the relevance and plausibility of each problem. Problems deemed to be irrelevant by students can demotivate them and also reduce the probability of them benefiting from the module [29]. Therefore, while previously published problem-based learning development guidelines [25, 26] do not formally include this step, the authors of this work suggest this step to ensure that the drafted problems are relevant and plausible to BIM-based projects in industry. This step will likely be especially crucial for future educational researchers who aim to create this type of learning module for more cutting-edge applications that may not have a wealth of previously published literature documenting the industry problems targeted.

For the modules developed to test the overarching methodology, this validation step was completed by bringing the drafted problem statements to industry practitioners who have BIM experience. These practitioners were asked to provide input on the plausibility of the developed statements. Specifically, these industry practitioners were asked to state whether or not they believed each problem statement was realistic, as written. Furthermore, they were also asked to provide specific suggestions for modifications that might make the problem statements more plausible. Based on the discussion, the authors modified the problems to reflect the input provided by the industry practitioners.

While this validation step does not require substantial additional effort by educators, it may prove to be highly valuable for the creation of problem statements. This can help to identify unforeseen issues with the developed content before it is distributed to the students. In turn, this may reduce the chances of students perceiving the problems as irrelevant. Furthermore, it may help to confirm that the targeted learning content is also addressing relevant industry needs as it is written.

3.2 Developing the lesson plan (Phase 2)

Once the problem modules were created, a lesson plan for implementing them was developed. Fig. 3 shows the general process for producing an effective lesson plan, as well as specific examples that were used for creating the BIM problem implementation strategy. Some of the strategies suggested for developing a lesson plan were reported by prior work, including Duch et al. [25], Delisle [26], and Kenney [30]. However, some of these strategies required modification to support BIM education contexts directly.

3.2.1 Selecting skills

Before educators can determine whether or not a developed BIM-based problem has had a beneficial impact on student learners, it is necessary to decide which skills they aim to improve through the module. For many educators, this will be a straightforward decision as they may already have a course with defined learning aims that indicate what skills would be most beneficial. For educators who do not know what skills may be most beneficial, the authors recommend referencing industry documents and colleagues that may be able to specify what types of skills or competencies may be needed among BIM professionals in order to target high-priority learning outcomes.

For this particular work, the authors leveraged prior research that was completed to identify the skills reported by industry practitioners as being necessary to resolve the identified people- and process-related issues for BIM projects [9]. These skills included: analytical and problem-solving, communication, initiative, planning and organizational, and teamwork. By using these previously identified

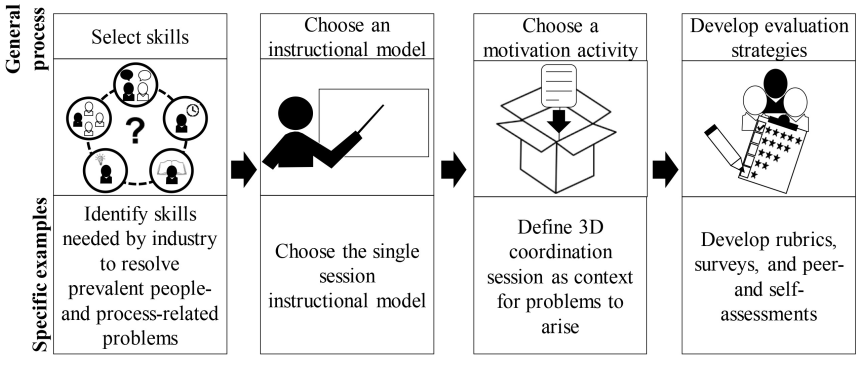

Fig. 3. Proposed methodology for generating implementation strategy for BIM-related

skills, it enabled the researchers to target the types of learning gains that may be most needed among construction professionals.

3.2.2 Choosing an instructional model

To incorporate problem-based learning effectively within an existing course, an instructional model must be selected that will support the specific needs and constraints of the given course. This decision may be based on several factors including the size of the class, the intellectual maturity of students, course objectives, preference of instructor, and availability of undergraduate peer tutors or graduate teaching assistants [25].

In the example modules developed in this work, the single session problem-based learning model by Kenney [30] was selected because the targeted class involves a weekly two-hour practicum session where students are provided with hands-on BIM education. This session enabled adequate time for students to dedicate to this learning activity and also provided an opportunity to align with the existing activity-based nature of this practicum session. The single session model involves students (i) analyzing the problem (ii) identifying, locating, and evaluating further information for solving the problem; (iii) consulting with team members on approaches for solving the problem; (iv) making decisions on the final strategy for solving the problem; and (v) reviewing their own performance with respect to the overall activity [30].

Furthermore, from a practical perspective, this single-session model offered plausibility to replicating the types of decision-making challenges that construction project leaders must face day-to-day when unforeseen problems arise due to people- or process-related BIM issues. In these instances, project leaders do not have the benefit of having a semester to determine a solution. Instead, they may need to define a resolution to a problem within a matter of hours. This single-session approach enabled the authors to replicate this type of decision-making challenge more accurately.

3.2.3 Choosing a motivation activity

Defining a useful motivation activity helps to ensure that students feel that the problem that they are tasked with resolving is important and worth their time and attention. Therefore, this step requires the instructor to think of ways to introduce the subject and make the links explicit [26]. For this work, the authors needed to target a motivation activity that would directly relate to the targeted student learners.

The motivating activity chosen involved students participating in a hypothetical BIM-based 3D coordination meeting. Coordination meetings involve comparing various contractor models to determine where clashes arise in the modeled content to resolve challenges before construction. These types of meetings are among the most common in construction [31, 32], most taught in schools [33], and considered to be among the essential BIM-related meetings in construction [34]. Furthermore, coordination meetings frequently involve different project participants, which make them a likely context for people- and process-related problems to arise. Students were told that they would play the role of a project manager for this meeting and would be able to determine solutions and policies to resolve the presented BIM problems. To further replicate the uncertainty of challenges that may arise in the students' subsequent careers, different problems that were developed were randomly selected by students. In all cases, once students chose their problem, they were required to define solutions to resolve the problem for the following coordination meeting and policies to resolve that problem for all future coordination meetings to the best of their ability.

3.2.4 Determining assessment strategies

Assessment strategies for problem-based learning can vary substantially. For each problem, educators must integrate an assessment strategy that can be used to evaluate the mastery of content, skills, and the process of problem-solving itself. The process of assessment in a problem-based learning classroom is encompassing in its methods, procedures, and goals [26]. For this work, the authors identified assessment strategies that would support the evaluation of the specific BIM educational goals.

The assessment strategies that have been suggested for evaluating the non-technological skills required for resolving the common BIM-based construction issues include rubrics, surveys, interviews, reflective journals, and peer-/self-evaluations [35]). From those assessment strategies, the authors chose to implement rubrics, surveys, and peer-/self-evaluations. Rubrics provide an approach to consistently evaluate student performance [36]. Surveys offer opportunities for students to give feedback on the module's impact on developing their skills [37]. Finally, self- and peer-evaluations provide a platform for critical reflection before giving feedback on the module's impact through the survey [38].

The methodology presented for defining BIM-related problem-based learning modules is intended to enable future educators to replicate this process to create different modules for other problem contexts related to BIM. To further illustrate how this process is applied, the proposed methodology section illustrates some of the key decisions that were made by the authors when developing their own BIM learning modules. In the subsequent results

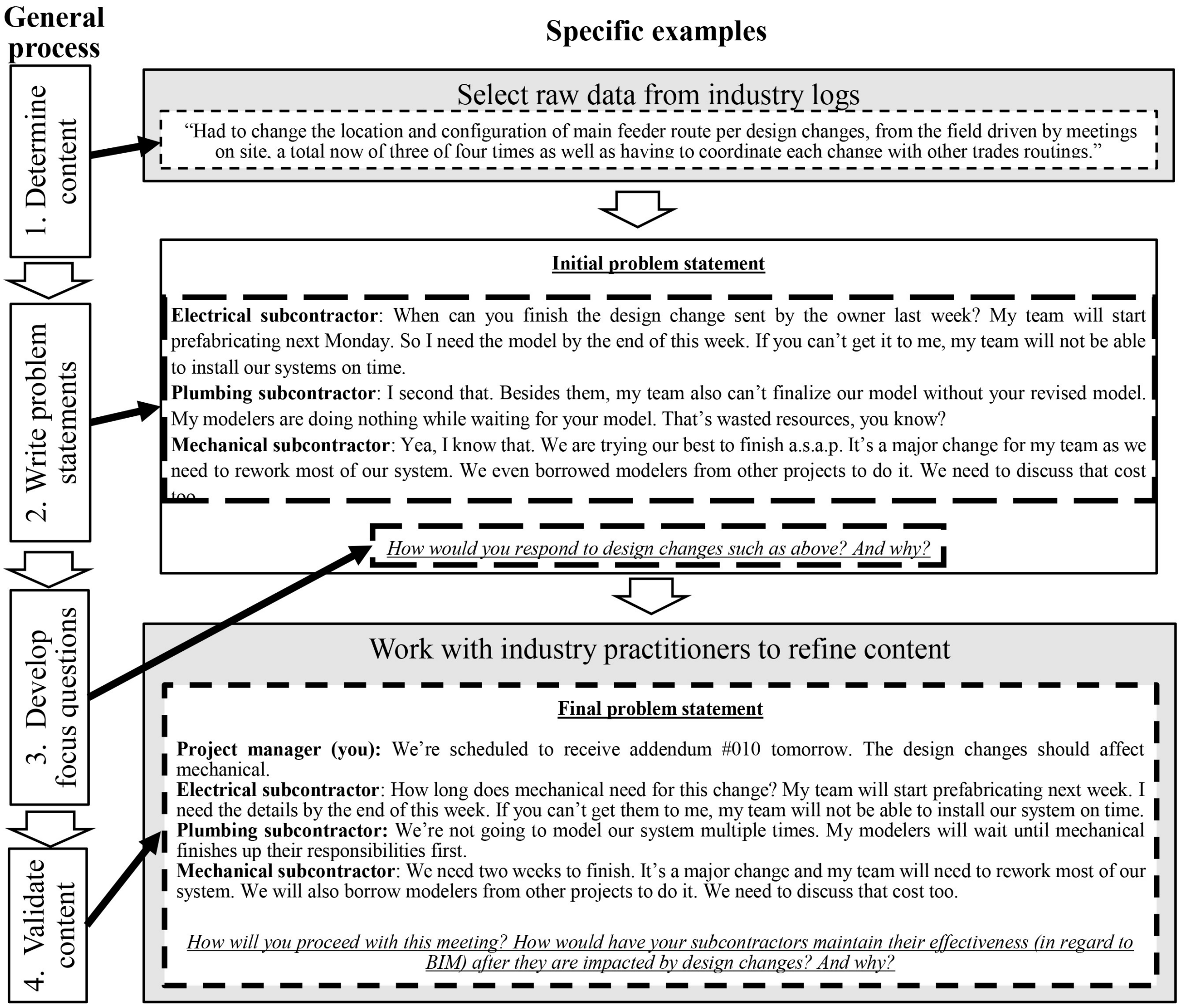

Fig. 4. An example of a BIM-related problem-based learning module based on the proposed development methodology.

and discussion section, examples of the developed modules are presented to illustrate the type of output that would be yielded through this methodology and relevant discussion is provided to support future educators who leverage this proposed methodology.

4. Results and discussion

The detailed method presented in the previous section is intended to allow future educators to develop BIM-related problem-based learning modules effectively. To test and validate that the methodology can indeed lead to relevant BIM learning modules, the authors developed several problem-based learning modules for BIM education according to the methodology presented in the prior sections. The developed content is shown in the subsequent sections to illustrate the resultant learning content that was generated from following the proposed process. This may help to provide a specific example to guide future researchers interested in leveraging this mode of education for other BIM-based educational topics.

4.1 The problem

Several BIM-based 3D coordination meeting problems were developed in this work to target the skills needed to resolve common people- and process-related issues that occur in construction projects. Fig. 4 shows an example of a learning module as it evolved through the methodology described in this paper. The initial content is from industry-generated problem logs. Then, the authors developed the problem logs into a dialogue between project team members to simulate the types of discussions that might be had in weekly BIM-based 3D coordination meetings. As mentioned in the methodology, the authors met with industry practitioners to validate the plausibility of the developed dialogue. The figure illustrates the types of changes that were suggested by the industry practitioners. This process of obtaining industry member feedback helped to add clarity to the problem statements and also helped to present content that is relevant to the problems currently faced in the industry.

Initially, eight problems were developed based on the four most common types of people- and process-related challenges observed on BIM-based construction projects (i.e., transfers of information, individual personalities, changes, and human error) [8]. Table 1 describes each of those issues as defined by Rahman and Ayer [8]. While all interviewees agreed that the common types of problems are indeed relevant to their work, one of the specific problem descriptions was suggested to be implausible by more than one interviewee. Therefore, even though this problem was created based on previously observed problem logs, the authors did not pursue the development of that particular problem because they aimed to target industry problems that were broadly relevant.

These findings suggest the process can assist educators in adding clarity to the module and removing content that is implausible in the industry. These changes can benefit the module because content that is timely and relevant to real life may increase students' motivation [27, 28]. In the near-term, this process benefits the development of the module. In the long-term, this study provides an approach that is repeatable as BIM evolves. Educators can use the approach to develop content that is relevant to the industry for their problem-based learning modules.

4.2 The lesson plan

As mentioned in the methodology, the examples developed in this work used the lesson plan structure by Kenney [30], which involved students role-playing as senior advisors for a senator and, within an hour, a problem emerged that required the students to help determine whether favoring or opposing an act would best support the senator's re-election. The lesson plan involved the students reviewing and analyzing the act; identifying, locating, and evaluating additional resources and information; consulting with team members, and making decisions on the recommendations for the senator.

The developed BIM module involved students role-playing as project managers for a hypothetical weekly 3D coordination meeting, which they must lead. Issues will emerge during that meeting, and each student will receive a problem statement in the form of a randomly chosen problem card. The problem cards present students with one of the specific problem narratives developed in this work. The activity required students to generate two outputs: (1) approaches to solve the problem immediately for the meeting (i.e., solutions); and (2) approaches to avoid the problem from recurring in the future (i.e., policies). To develop these outputs, the activity involves students:

(a) brainstorming up to three solutions and three policies without referring to any resources nor discussing with other individuals;
(b) determining the best solution and the best policy from the ideas that were brainstormed;
(c) searching the internet to identify additional resources to generate up to three new solutions and three new policies or to modify those created in the prior phases;
(d) discussing their developed concepts with other students who selected the same problem card to determine the group's best solutions and policies; and
(e) generating a final solution and a final policy to resolve the problem in the short- and long-term, respectively.

4.3 The assessments

The authors used questionnaire surveys and peer-/self-evaluation assessments that were partially adopted from assessments presented in various prior works. In this process of using previously published assessments, some content had to be modified to remove overlapping or unrelated content. The feedback form adopted assessments from two studies [39, 40]. The self- and peer-evaluations adopted assessments from three studies [41–43]. The

Table 1. Definition of the common people-and process-related issues

Issue	Definition
Transfers of Information	Instances on projects when individuals needed to exchange some type of information.
Changes	Complications that are caused by any acts or instances in which something becomes different at any time during the project.
Human error	Something that has been done that was not the intention of an individual. Providing incorrect or incomplete information, misinterpreting information, making mistakes during modeling, and "misclicks" in the model are included in the scope of human error.
Individual personalities	Difficulties that are either a combination of individual characteristics and qualities or one of those elements respectively. However, this issue excludes "human error."

Definition adopted from Rahman and Ayer (2017a).

authors chose to use a four-point Likert-scale without a "neutral" response. The questionnaire survey and peer/self-evaluation forms used in this work are presented in the appendix for reference.

The authors also adopt rubrics for evaluating the specific, measurable, assignable, realistic, and time-based (S.M.A.R.T.) criteria to evaluate the module's impact on students. These criteria were originally defined for setting goals and objectives in business applications [44]. While they were not originally designed for BIM-specific applications, they align very closely with the activities targeted in this work. For instance, instead of requiring students to set business goals and objectives, they were required to define plans of action for addressing BIM problems, which is analogous in terms of the required thought outputs. Beyond just making practical sense, the individual S.M.A.R.T. criteria have been reported to be linked to the explicitly targeted learning skills:

- Specific can be associated with the ability to identify and solve problems and implement effective solutions (i.e., problem-solving skills) [45].
- Measurable can be associated with the ability to predict changes (i.e., organizational skills) [46].
- Assignable can be related to the ability to allocate resources to implement initiatives appropriately (i.e., organizational skills) [46].
- Realistic can be associated with practical intelligence (i.e., analytical skills) [47].
- Time-based can be related to the ability to plan (i.e., analytical skills) [47].

In addition to the specific ties between S.M.A.R.T. and the targeted skills, using the S.M.A.R.T. criteria to evaluate students in a BIM context enabled the authors to leverage a previously-validated rubric that closely aligned with their targeted learning outcomes. The S.M.A.R.T. rubric adopted in this study is presented in this paper's appendix.

4.4 Validating the learning module

The methodology proposed in this work was successful at yielding a BIM-related problem-based learning module, as presented in the prior sections. However, beyond simply creating a module, the authors needed to ensure that the developed module would address the targeted learning topics. Therefore, all developed learning module content was validated through expert interviews with current industry professionals who interact with BIM in a professional capacity. The proposed module development process includes validation steps that strategically elicit input from industry practitioners to ensure that the developed content has external validity. This portion of the methodology not only enabled the researchers to develop BIM learning modules that were reported to be plausible by industry practitioners, but it also includes this critical verification activity for future educators. Therefore, the authors believe that these steps not only helped to validate the quality of the module developed for people- and process-related BIM issues, but also that it would be beneficial for any future educators targeting BIM education through problem-based learning. As BIM continues to evolve, current practitioners can offer a wealth of up-to-date knowledge to support the development of educational tools that offer not only theoretical validity (according to the literature that guides problem-based learning module development), but also practical validity that will enable modules to address critical, and current, industry needs.

In addition to validating the problem-based learning modules developed using the industry practitioners' expertise, the authors have also tested these modules with students to determine their effectiveness. Specific results for these implementations have been documented in other publications [9]. For a methodological paper aimed at demonstrating a process that can be used to define BIM-related problem-based learning modules from industry data, the authors believed it would be unwise to test a PBL module with students if it had not been first validated with industry practitioners who know the targeted context for implementation. Therefore, the focus of validation for this work relates to the developed problem-based learning module content itself.

4.5 Limitations

This study provides a methodology that may be used to develop problem-based learning modules to support BIM education. It also offers validation of that process through the involvement of current industry practitioners that use BIM. However, the authors cannot make claims about the exact extent to which the developed example modules impact student performance, because it does not present data from actual implementations with students. While this limits the extent to which they can claim educational benefits from the specific module developed, problem-based learning as a mode of education has been well documented to illustrate its benefits [21, 49, 50]. Furthermore, the exact skills targeted in this work have been suggested to benefit directly from problem-based learning. Perhaps most importantly, the prior works that have reported value to problem-based learning have not aimed to provide a method that can support educators in developing BIM-related problem-based learning modules. Therefore, while the authors cannot claim the exact extent to which this module would impact student performance, they believe that validating the underlying process for creating plausible learning modules (as confirmed by industry practitioners) may be more beneficial for future researchers interested in leveraging this mode of education.

5. Conclusion

This work presents a methodology for developing a problem-based learning module for BIM education. Where possible, the authors suggest leveraging existing development and assessment strategies for problem-based learning module development. However, for some development tasks, existing strategies may not directly relate to BIM education. Therefore, the authors provide suggestions and examples of how they developed learning modules that can relate to BIM. The proposed methodology successfully led the authors to the creation of a BIM-based learning module and assessment strategy. Furthermore, interviews with industry practitioners who work with BIM validated the plausibility of the resultant module.

Future educators may use this methodology to develop subsequent BIM-related problem-based learning modules. This may be especially necessary as the needs of BIM professionals are likely to evolve in the future. Similarly, the types of problems that support effective education to prepare future construction managers may also need to evolve. This methodology will enable educators to use a structured and consistent methodology to develop new modules that will be able to remain current with industry needs because of strategic involvement of industry professionals in the proposed development method.

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Appendix

Feedback form for this study's learning module

I feel that:	Strongly disagree	Disagree	Agree	Strongly agree
The activity has enhanced my problem-solving skills	1	2	3	4
The activity has enhanced my analytical skills	1	2	3	4
The activity has enhanced my ability to work as a team member	1	2	3	4
The activity has enhanced my communication skills	1	2	3	4
The content reflected real-world issues that will help with future professional experience	1	2	3	4
Overall, I was satisfied with the quality of the activity	1	2	3	4
The activity should be used in future BIM courses	1	2	3	4

The S.M.A.R.T. rubric for this study's learning module

Criterion/Score	3 points	2 points	1 points
Specific	Has a strong connection to solving the problem	Has some connection to solving the problem	Has no connection to solving the problem
Measurable	Has clear criteria for measuring progress	Has unclear criteria for measuring progress	Has no criteria for measuring progress
Assignable	Has tasks that are clearly assigned to certain individuals or groups	Has tasks that are somewhat assigned to certain individuals or groups	Has tasks that are not assigned to any individuals or groups
Realistic	Can be executed	Can probably be executed	Cannot be executed
Time-related	Has a clear time-frame for accomplishing certain goals	Has an unclear time-frame for accomplishing certain goals	Has no time-frame for accomplishing certain goals

Peer- and self-evaluations for this study's learning module

When performing the activity, I felt that I/______ (insert name of team member)	Strongly disagree	Disagree	Agree	Strongly agree
Was able to share ideas clearly with the group	1	2	3	4
Actively participated in the group discussion	1	2	3	4
Gave input which was relevant to the problem	1	2	3	4
Actively tried to think how to use resources to solve the problem	1	2	3	4
Was able to solve the problem	1	2	3	4

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