

## ENHANCING THE NON-TECHNOLOGICAL SKILLS REQUIRED FOR EFFECTIVE BUILDING INFORMATION MODELING THROUGH PROBLEM-BASED LEARNING

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**SUMMARY:** *Building Information Modeling (BIM) is often associated with the use of new and emerging technologies, but prior research has indicated that non-technological, people- and process-related, issues can hinder the success of BIM even more than the technology itself. Previous work also suggests that analytical and problem-solving, communication, initiative, planning and organizational, and teamwork competencies among construction professionals can help to resolve the most common BIM issues in construction projects. This indicates a new and complementary set of BIM skills that may need to be targeted by educators when preparing students for successful future careers. Previous literature from non-BIM domains suggests that problem-based learning can enhance these types of skills, but there is not an understanding of the extent to which this mode of education can benefit BIM-specific applications. This study aims to analyze the impact of implementing a single-session problem-based learning module that targets the previously identified skills in BIM-relevant contexts. It was found that problem-based learning enabled students to generate better outputs related to solving common issues in BIM-based construction projects. Furthermore, students perceived improvements in their analytical and problem-solving, teamwork, and communications skills after completing the activity. This study adds to the body of knowledge by providing educators with empirical evidence to illustrate how problem-based learning can support BIM education. The lessons from this study could help educators target these same learning benefits in future studies.*

**KEYWORDS:** *Building Information Modeling (BIM), problem-based learning, skills, S.M.A.R.T. (specific, measurable, assignable, realistic, & time-based)*

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## 1. INTRODUCTION

Building Information Modeling (BIM) is a set of technologies and processes that enable project team members to virtually represent information throughout the lifecycle of a construction project that supports efficient design, information storage and retrieval, model-based data analysis, decision making, and communication among project stakeholders (Eastman et al, 2011). The use of BIM is becoming a standard practice in major construction projects in the United States (McGraw-Hill Construction 2014). Architecture, engineering, and construction (AEC) companies are adopting BIM because of its benefits, which include cost reduction and control through the project life cycle, time savings, and potentially high return on investment (Azhar 2011, Bryde et al, 2013, Giel and Issa 2011).

While BIM has many potential benefits, implementation issues on projects can hinder the realization of those benefits (Ghaffarianhoseini et al, 2017). These issues include those such as technical and managerial difficulties, and lack of alignment among stakeholders (Azhar, 2011, Hamdi and Leite, 2013). Furthermore, specific issues such as coordination between project activities and change resistance among individuals can inhibit the success of implementing BIM in construction projects (Tulenheimo, 2015). Therefore, having project team members with the skills for resolving or avoiding issues in BIM-based construction projects is necessary to reap the benefits of implementing BIM.

Technology, people, and processes can all influence the impact of implementing BIM in construction projects (Arayici et al, 2011). However, people and processes are the most common causes of issues that lead to problems or difficulties in BIM-based construction projects (Rahman and Ayer, 2017). Specifically, the most common people- and process-related issues are: 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) (Rahman and Ayer, 2017). In other words, while new and emerging technologies are a core component of effective BIM implementation, the majority of problems are not the result of technology, but instead the result of people and processes related to those technologies.

Expert interviews revealed that communication, analytical and problem-solving, planning and organizational, initiative, and teamwork skills are the most necessary for BIM professionals to have to successfully avoid and resolve the common, non-technological, issues related to BIM (Rahman, 2018). While problem-based learning has been suggested to enhance most of these skills in non-BIM domains, there is a lack of literature on the actual impact of implementing this mode of education in the non-technological skills that are critical to successful BIM implementation. Therefore, the objective of this paper is to determine the extent to which problem-based learning can enable students to demonstrate improvement in the targeted non-technological skills required for successful BIM implementation.

The authors address this objective by implementing a problem-based learning module in an undergraduate BIM course and analyzing the collected data from the implementation. The findings contribute to the current body of knowledge in two main ways. They provide educators with empirical data to illustrate how problem-based learning may support the development of targeted skills required for effective BIM implementation. Furthermore, this paper offers a deployment and assessment methodology that may be used by future educators to target the learning gains reported or to measure the success of new problem-based learning modules developed.

## 2. BACKGROUND

### 2.1 Teaching the non-technological skills of BIM

Analytical and problem-solving, communication, initiative, planning and organizational, and teamwork skills have been suggested to be the most critical skills for BIM professionals to have to resolve the most common people- and process-related issues that can arise in BIM projects (Rahman, 2018). To enhance these skills among students in BIM contexts, educators have experimented with various teaching strategies including case studies and project-based learning (Russell et al, 2014, Wang and Leite, 2014). Researchers in other, non-BIM-related, educational domains have demonstrated the potential of problem-based learning for enhancing some of the same skills as those required for BIM (Steinmann 2003, Ribeiro and Mizukami 2005, Quinn and Albano 2008).

There is also a small body of literature that has explored problem-based learning in BIM-related contexts, but these prior works have not generally aimed to target the same set of skills or implementation strategy examined in this

paper. For example, problem-based learning has been tested at a program-wide level, where educators aimed to incorporate a single project that could provide context for students learning various construction-related course topics through the lens of BIM (Forsythe et al, 2013). Additionally, problem-based learning modules were implemented throughout a semester in a BIM course and observed several benefits using explicitly measured outcomes (i.e., positive peer evaluations and student evaluations of the overall course), as well implicitly measured results (i.e., students successfully receiving BIM-related job offers after completing the course) (Leite, 2016). Both of these prior works suggest potential benefits to using problem-based learning for BIM, but they suggest these benefits through relatively intensive means of delivering this content that require buy-in either for an entire program or for a whole course (Forsythe et al, 2013, Leite, 2016).

The authors of this paper aimed to explore the extent to which BIM-based learning benefits from problem-based learning may be observable through a single-session learning module. A single session module offers practical benefits for both educators and practitioners. This can allow educators to more easily incorporate BIM-based problem-based learning modules into existing courses or practitioners to conduct lunch-and-learn style sessions for training team members on a BIM project. However, the extent to which this form of single-session problem-based learning can support the targeted skill development required for BIM implementation is not clear. Prior researchers from non-BIM fields have indicated that single-session problem-based learning modules may promote students' skill development related to information literacy (Kenney, 2008), which offers theoretical value to implementing this mode of education for BIM contexts.

## 2.2 Assessing learning modules through implementation

While previously referenced work (Kenney, 2008) suggests theoretical value to a single-session problem-based learning module, this value has not yet been observed through application in a BIM context. Educational researchers in the AEC realm regularly publish literature on the implementation of new and emerging educational modules to validate their efficacy. For example, numerous researchers have identified the impact of adopting problem-based learning in teaching courses including engineering surveying, structural, and construction management (Williams and Pender 2002; Lam 2008; Quinn and Albano, 2008). Additionally, the potential benefits of using problem-based learning in teaching certain content such as the critical path method, sustainability, and safety have been determined (Steinemann, 2003; El-adaway et al. 2014; Forcael et al. 2014; Vidic 2015). Furthermore, the impact of adopting new or alternative pedagogies for BIM education have also been investigated including team-based learning, project-based learning, and collaborative learning (Leite, 2016; Bozolgu 2016, Zhang et al. 2018). These studies illustrate that, even when there is theoretical evidence to suggest value to new and emerging educational strategies, empirical studies that implement those strategies offer research contributions by helping readers understand the extent to which the theoretical value is observed.

## 2.3 The learning module

To identify the impact of problem-based learning on the targeted skills (i.e., analytical and problem-solving, communication, initiative, planning and organizational, and teamwork, hereinafter the “targeted skills”), the authors have developed a one-session problem-based learning module that explicitly targets those skills, as detailed in Rahman (2018). The learning module involves students role-playing as project managers for a hypothetical weekly BIM-based 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 problem cards randomly. The problem cards present students with a specific problem narrative that outlines the challenge that they must resolve. An example problem narrative is included in Table 1.

TABLE. 1: An example of the learning module's problem card.

<p><b>Electrical subcontractor:</b> Our team has uploaded our deliverables for this session. However, some parts are incomplete.</p> <p><b>Project manager (you):</b> Oh, can you explain to me why that is?</p> <p><b>Electrical subcontractor:</b> We are awaiting information on both the RFI submitted to the field to route the conduit through potential block-outs in the beam and on the incomplete lighting cut sheets from the lighting vendors. We are also awaiting sheet metal to complete their changes from addendum #013.</p> <p><i>How will you proceed with this meeting? How will you handle subcontractors that are unable to provide their deliverables from not having the necessary information in the future? And why?</i></p>
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The activity requires students to generate two outputs throughout various thought exercises during the activity, including: (1) approaches to solve the problem in the immediate short-term (i.e., solutions); and (2) approaches to avoid the problem from recurring in the future (i.e., policies). To develop these outputs, several thought exercises throughout the activity guide students to:

- brainstorm up to three solutions and three policies without referring to any resources nor discussing with other individuals;
- determine what they believe to be the best solution and the best policy from the ideas that were brainstormed;
- search the internet to identify other resources to generate up to three new solutions and three new policies or to modify those created in the prior phases;
- discuss their developed concepts with other students who selected the same problem card to determine the best solutions and policies generated among the group; and
- generate a final solution and a final policy to resolve the problem in the short- and long-term, respectively.

Fig. 1 outlines the learning module.

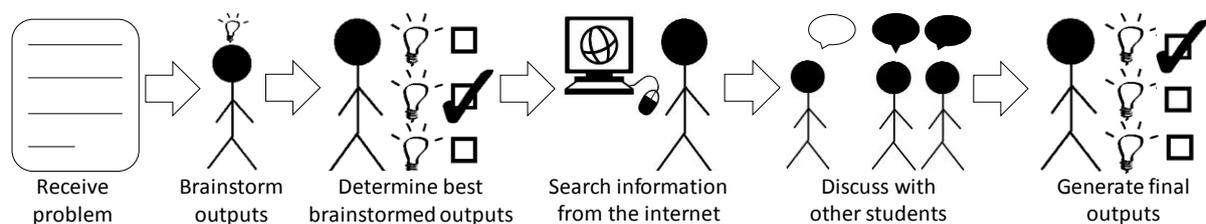


FIG 1: Overview of the learning module.

To assess the impact of problem-based learning on the targeted skills, rubrics, surveys, and peer-/self-assessments were used. Surveys can allow students to provide feedback on the module's impact on developing their skills (Richardson, 2005). Peer- and self-assessments can support critical reflection among students (Nicol and Macfarlane-Dick, 2006). Finally, rubrics provide an approach to consistently evaluate student performance (Arter and McTighe, 2000).

The specific, measurable, assignable, realistic, and time-based (S.M.A.R.T.) rubric was adopted for this study because it provides an efficient and valid means to assess the quality of student responses (Doran, 1981). This rubric has been used by other researchers for assessing the quality of student responses to ill-structured, and open-ended, problems that are typically incorporated into problem-based learning (Divall et al, 2014). Furthermore, previous research has suggested links between the S.M.A.R.T. criteria and the skills that were specifically targeted in this work:

- Specific can be associated with the ability to identify and solve problems and implement effective solutions (i.e., problem-solving skills) (Leicht et al, 2009).
- Measurable can be associated with the ability to predict changes (i.e., organizational skills) (Giesecke and McNeil, 1999)
- Assignable can be related to the ability to allocate resources to implement initiatives appropriately (i.e., organizational skills) (Giesecke and McNeil, 1999).
- Realistic can be associated with practical intelligence (i.e., analytical skills) (Rainsbury et al, 2002)
- Time-based can be related to the ability to plan (i.e., planning skills) (Rainsbury et al, 2002)
- In addition to associations between individual S.M.A.R.T. criteria and the targeted skills, prior research also suggests that the aggregated S.M.A.R.T. scores can be used to assess communication skill (Lockspeiser et al, 2013).

In addition to providing assessments related to the targeted skills, the S.M.A.R.T. rubric organizes assessments into five categories that can be easily understood by individuals reviewing their work as well as their peers' (Reed et al, 2016). Therefore, the authors chose this rubric to allow students without substantial prior experience using the rubric to be able to provide an effective assessment. Additionally, avoiding exhaustion or extreme tiredness in individuals is crucial in ensuring data reliability because exhausted participants tend to lose attention during the data collection process and provide answers with a lower quality (Kumar and Phrommathed, 2005). Therefore,

this study adopts the SMART rubric because the simple structure may help students to use it throughout the activity without this fatigue. The exact rubric text used for this work is shown in Table 2.

TABLE. 2: The S.M.A.R.T. rubric for this study's learning module.

Criterion/Score	3 points	2 points	1 points
<u>S</u> pecific	Has a strong connection to solving the problem	Has some connection to solving the problem	Has no connection to solving the problem
<u>M</u> easurable	Has clear criteria for measuring progress	Has unclear criteria for measuring progress	Has no criteria for measuring progress
<u>A</u> ssignable	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
<u>R</u> ealistic	Can be executed	Can probably be executed	Cannot be executed
<u>T</u> ime-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

In addition to the S.M.A.R.T. rubric, the authors also used questionnaire surveys to solicit student perceptions about the activity, as shown in Table 3. Studies show that Likert-scales with a “neutral” option can significantly increase the number of people stating they have no opinion, even when they do have an opinion (Krosnick and Presser 2010). Therefore, this study adopts a four-point Likert-scale to eliminate this possibility.

TABLE. 3: Feedback form for this study's learning module.

I feel that:	Strongly disagree	Disagree	Agree	Strongly agree
Likert-type scale questions				
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
Open-ended questions				
What are the main strengths of the activity?				
How can the activity be further improved?				
If you have any other thoughts, comments or feedback on this activity, please include them below				

### 3. METHODOLOGY

Data was collected through implementing the learning module with students and also by collecting evaluations of the student responses from industry practitioners. The collected data was analyzed to identify noteworthy trends and changes in student performance during the activity. Section 3.1 and 3.2 provide details for each of these steps.

#### 3.1 Data collection

In order to collect data for this study, students enrolled in a BIM-focused Project Management course were studied during the Fall 2017 and Spring 2018 semesters at Arizona State University. Subsequently, the responses and feedback generated by the students were reviewed by industry practitioners that have responsibilities directly related to BIM to help provide an external assessment of the behaviors and performance of the students.

As detailed in section 2.3, a previously developed problem-based learning module related to the non-technological aspects of BIM was implemented over these semesters. In both semesters, students were tasked with selecting a random problem card that would illustrate a people- or process-related BIM problem that they would have to solve. For example, they could receive a card stating that one of their subcontractors failed to deliver an updated model for a BIM coordination session as required. After receiving problem cards, students would conduct the thought exercises involved in the module to determine their best possible solution and policy for resolving the selected problem in the immediate and distant future.

While the problems and general format of the activities were consistent between both Fall 2017 and Spring 2018, some differences were present in the sessions related to the researchers' data collection strategy. These differences are presented in section 3.1.1, 3.1.2, and 3.1.3. Fig. 2 summarizes the data collection procedure for both the Fall 2017 and Spring 2018 students.



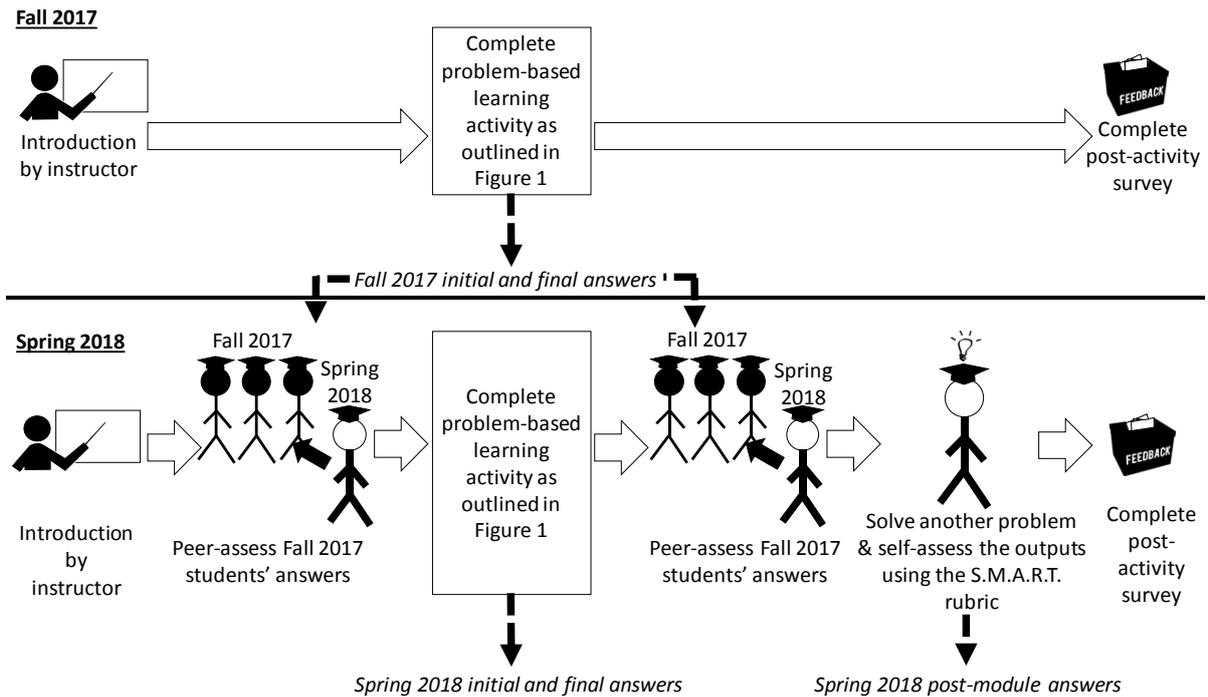


FIG 2: The procedure for collecting data from the Fall 2017 and Spring 2018 students.

### 3.1.1 Students from Fall 2017

When implementing the module for the Fall 2017 session, students provided their:

- Best solution and best policy from the ideas that were brainstormed (i.e., initial answers)
- Final solution and final policy to resolve the problem (i.e., final answers)
- Self-evaluation using the S.M.A.R.T. rubric for each of their answers.

Collecting those responses with their self-evaluated S.M.A.R.T. evaluations allows the authors to provide the students' answers to other individuals for evaluation purposes, and also to compare the self-evaluated initial and final scores

### 3.1.2 Students from Spring 2018

For the Spring 2018 session, in addition to implementing the learning module, the authors required the students to evaluate the quality of the Fall 2017 students' answers based on the S.M.A.R.T. criteria; and also solve another problem and self-evaluate their answers to that new problem using the S.M.A.R.T. rubric. These additions provide the study with peer-evaluations of the Fall 2017 students' responses using the S.M.A.R.T. rubric. This also helped to provide an opportunity for the researchers to see if students' self-evaluations were different when evaluating a newly created solution and policy to a new problem card after completing the sequential thought exercises included in the original problem-based learning module.

To facilitate these additions, the authors provided the Spring 2018 students with the answers provided by Fall 2017 students for two different problem statements. All Spring 2018 students were provided with responses to a problem that was different from the type of problem that they had selected as their problem card. For example, if a student chose a problem card with an issue associated with 'individual personalities' during the activity, the student would not evaluate answers to that problem or any other problems associated with individual personalities before or after the activity. This setup reduced the chances of Spring 2018 students from being able to directly use the answers provided by the Fall 2017 students when addressing their problem. Also, the Fall 2017 students' answers were arranged randomly so that students would not know whether the answers they were evaluating came from the beginning or end of the problem-based learning activity. Theoretically, if students knew that a response came from the end of the activity, they could be inclined to rate it more highly because they believe it is supposed to be better from this fact alone. This helped to reduce the chances of bias from the student evaluations.

In addition to collecting the Spring 2018 students' evaluations of the prior semesters' students' responses, the Spring 2018 students were also tasked with trying to resolve a follow-up problem without following the structured problem-based learning module thought process. Specifically, after the students completed the learning module (hereafter Spring 2018 answers), the students were asked to evaluate prior semesters' answers for a problem card other than the one they were originally assigned. Then after the students provided their evaluations, the students were tasked with resolving that new problem by providing a solution and policy (hereafter Spring 2018 post-module answers). This was done to determine the extent to which the quality of responses generated for this new problem, for which students did not follow the same formalized thought activities, would align with the evaluations of responses from the original problem.

### 3.1.3 Industry practitioners' evaluations

To provide expert evaluations of the students' responses, industry practitioners evaluated the Fall 2017 students' initial and final answers using the S.M.A.R.T. rubric. The practitioners included individuals from different companies and various stakeholders that have responsibilities directly related to BIM. The selected practitioners were asked to evaluate verbatim responses generated by the students during the activity. To reduce any potential bias from industry experts knowing whether a student's answer was provided at the beginning or end of the session, the Fall 2017 students' answers were arranged randomly. This meant that the practitioners would only be able to evaluate the students' responses based on their content and not based on whether the responses came from the beginning or end of the activity. This was done to reduce the possibility of practitioners subconsciously evaluating final responses more favorably than initial responses because they believed they were supposed to be better.

The practitioners were given the same set of responses that were given to the Spring 2018 students. This allowed the authors to identify any differences between the practitioners' and Spring 2018 students' evaluations. Furthermore, it helped to determine the extent to which students and practitioners evaluated the responses similarly or differently.

## 3.2 Data analysis

### 3.2.1 Scores from evaluations using the S.M.A.R.T. rubric

The S.M.A.R.T. rubric (Table 3) has a scoring system of minimum 1 point and maximum 3 points for each criterion. Because there are five components to S.M.A.R.T., the minimum and maximum total scores for answers are 5 points and 15 points, respectively. The scoring system's overall scores and individual criterion scores are used to compare the module's impact on the S.M.A.R.T. scores among students' answers when addressing: (i) the same problem throughout the activity; and (ii) another problem post-module. Table 4 presents the data points used for those comparisons. For each comparison, S.M.A.R.T. evaluations of various student-developed outputs (i.e., solutions and policies) were compared. For all comparisons, the Wilcoxon signed-rank test was used to identify any statistical differences in the comparisons. The authors used that test because the S.M.A.R.T. rubric produces ordinal variables and the test compares two dependent samples with ordinal variables for the difference in population means (Gibbons and Chakraborti, 2011).

TABLE 4: Type of comparisons and their rationale when analyzing the S.M.A.R.T. scores.

Comparison between		Rationale for comparison
Data Point 1	Data Point 2	
(Fall 2017/Spring 2018) self-evaluation: initial answers	(Fall 2017/Spring 2018) self-evaluation: final answers	Identify the module's perceived impact on the S.M.A.R.T. scores
Spring 2018 peer-evaluation: Fall 2017 initial answers	Spring 2018 peer-evaluation: Fall 2017 final answers	Identify the module's impact on peer-reviewed S.M.A.R.T. scores
Practitioners' evaluation: Fall 2017 initial answers	Practitioners' evaluation: Fall 2017 final answers	Identify the module's impact on industry practitioner-reviewed S.M.A.R.T. scores
Spring 2018 self-evaluation: initial answers	Spring 2018 self-evaluation: post-module answers	Identify the perceived quality of their initial responses to a problem after completing the problem-based learning module
Spring 2018 self-evaluation: final answers	Spring 2018 self-evaluation: post-module answers	Identify the perceived impact of the module's structured thought exercises on S.M.A.R.T. scores

### 3.2.2 Students' feedback from the post-activity survey

In addition to analyzing the scores for the S.M.A.R.T. criteria, the students' feedback of the learning activity from the post-activity survey was also analyzed. This additional data included responses to the Likert style questions included in Table 3. This analysis indicates the students' perceptions about the extent to which the activity enhanced the targeted skills. Furthermore, the open-ended questions were analyzed to identify any additional information reported by the students, including feelings, attitudes, and understandings of relevant information related to the problem-based learning activity.

## 4. RESULTS

The Fall 2017 semester included 55 students who completed all portions of the learning module and agreed to participate in this research. Each of these students evaluated the 4 outputs they created (initial solution, initial policy, final solution, and final policy), yielding 220 self-evaluation data points from the Fall 2017 semester. The Spring 2018 semester included 46 students who completed all portions of the activity and consented to participate in the research. Each student evaluated the 6 outputs they created (initial solution, initial policy, final solution, final policy, post-module solution, and post-module policy), which provided 276 self-evaluation data points. In addition to providing self-evaluations, the Spring 2018 students peer-evaluated each of the Fall 2017 students' 4 outputs 2 times (i.e., 8 evaluations provided per student), providing 368 peer-evaluation data points. The Fall 2017 and Spring 2018 students are primarily fourth-year students in their final year of school, with a few third-year students. All students in this course have completed at least an internship before taking the course. Many students had multiple internships, and some also had full-time work experience before taking the class.

The industry practitioners who evaluated student responses included 11 individuals. Each practitioner evaluated 6 of each of the Fall 2017 students' 4 outputs (i.e., 24 evaluations provided per practitioner). This provided 264 data points from these external evaluators. The industry practitioners are individuals of different companies that the authors selected because of their in-depth knowledge and experience with BIM in the industry. Five of them are from Phoenix, AZ, near the authors' academic institution, while the other 6 are from other states throughout the United States.

### 4.1 Module's impact on S.M.A.R.T. scores

TABLE 5: The average S.M.A.R.T. scores from all evaluators for the Fall 2017 students' answers.

Evaluator	Self (Fall 2017 students)			Peer (Spring 2018 students)			Industry practitioners		
	Initial ( $S^I$ )	Final ( $S^F$ )	$S^F - S^I$	Initial ( $P^I$ )	Final ( $P^F$ )	$P^F - P^I$	Initial ( $I^I$ )	Final ( $I^F$ )	$I^F - I^I$
<b>Solution</b>									
Specific	2.76	2.91	0.15*	2.26	2.52	0.26*	2.03	2.28	0.25*
Measurable	2.55	2.82	0.27*	1.92	2.35	0.42*	1.88	1.92	0.04
Assignable	2.71	2.87	0.16*	2.21	2.62	0.41*	2.10	2.11	0.01
Realistic	2.80	2.94	0.14	2.36	2.55	0.20*	2.03	2.11	0.08
Time-based	2.40	2.80	0.40*	1.87	2.37	0.50*	1.63	2.10	0.47*
Overall	13.22	14.35	1.13*	10.62	12.41	1.79*	9.65	10.51	0.86*
<b>Policy</b>									
Specific	2.67	2.93	0.25*	2.28	2.55	0.27*	1.92	2.14	0.22*
Measurable	2.51	2.87	0.36*	2.08	2.42	0.35*	2.00	2.19	0.19
Assignable	2.49	2.84	0.35*	2.18	2.48	0.29*	2.04	2.15	0.11
Realistic	2.80	2.89	0.09	2.28	2.49	0.21*	1.74	2.10	0.36*
Time-based	2.45	2.91	0.45*	2.12	2.37	0.25*	1.94	2.07	0.13*
Overall	12.93	14.44	1.51*	10.95	12.32	1.37*	9.64	10.65	1.01*

\* Final scores that are significantly different from the initial scores at  $p < 0.05$  from the Wilcoxon signed-rank test.

Table 5 presents the changes between the S.M.A.R.T. scores' mean between the initial and final answers. The results show a significant increase in the overall scores by all evaluators (i.e., students' self-evaluation, students' peer-evaluation, and industry practitioners' external-evaluation). The finding that students' evaluate their work more highly after completing the exercise is largely intuitive. Students knew that they were participating in a research activity aimed at improving BIM education. Therefore, it is possible that they consciously or

subconsciously inflated their S.M.A.R.T. scores toward the end of the activity because they believed they were supposed to see improvement in their performance. However, when examining the scores received by their peers in a different semester and also by industry practitioners who did not know which responses came from the beginning or end of the activity, it was noteworthy to see that these scores also illustrated an increase in the overall S.M.A.R.T. scores. This suggests that problem-based learning leads to improved scores related to the S.M.A.R.T. criteria among students' answers for addressing a problem statement related to common issues in BIM-based construction projects.

While the results show increases in the overall scores regardless of the evaluator, there is a lack of significant changes in certain specific elements within these criteria. For example, the researchers did not observe a significant shift in students' self-evaluations related to the 'realistic' criterion for policies. Realism often relates to the practical ability for a solution or policy to be implemented (Doran, 1981). This may be influenced by the attributes of a project or team that fall outside the scope of the specific problem statement that was presented to the students. This means that students may have to make what they believe to be logical assumptions about this context. If a student evaluates his or her responses based on this category, that individual would likely maintain the same assumptions through the activity, which may explain the comparatively high mean scores associated with this criterion throughout the activity. As a result, this high mean does not indicate a significant shift in the students' self-evaluations of this S.M.A.R.T. criterion.

In addition to a lack of significance in realism among students' self-evaluations, the researchers also did not observe significant shifts in practitioners' evaluations of the 'measurable,' 'assignable,' and 'realistic' criteria for solutions, and 'measurable' and 'assignable' for policies. This may be attributed to the different behaviors of individuals with industrial experience (i.e., the industry practitioners) and without industrial experience (i.e., the students) (Walker et al 2005, Gruenther et al 2009). This suggests that while student evaluations can show problem-based learning leads to improved scores, evaluators with more experience may not report the same type of positive shift.

#### 4.2 Module's impact on S.M.A.R.T. scores for another problem

TABLE. 6: Students' self-evaluation of their responses using the S.M.A.R.T. rubric for the Spring 2018 session.

Answer	Initial	Final	Post-module			
Problem	1 <sup>st</sup> problem ( $S^{18}_I$ )	1 <sup>st</sup> problem ( $S^{18}_F$ )	2 <sup>nd</sup> problem ( $S^{18}_{2nd}$ )	$S^{18}_F - S^{18}_I$	$S^{18}_{2nd} - S^{18}_I$	$S^{18}_F - S^{18}_{2nd}$
<b>Solution</b>						
Specific	2.76	2.93	2.83	0.17*	0.07	0.11*
Measurable	2.35	2.85	2.67	0.50*	0.33*	0.17*
Assignable	2.63	2.91	2.74	0.28*	0.11	0.17*
Realistic	2.72	2.93	2.83	0.22*	0.11	0.11*
Time-based	2.37	2.70	2.60	0.33*	0.23*	0.10
Overall	12.83	14.33	13.65	1.50*	0.83*	0.67*
<b>Policy</b>						
Specific	2.63	2.91	2.85	0.28*	0.22*	0.07
Measurable	2.43	2.85	2.65	0.41*	0.22*	0.20*
Assignable	2.67	2.91	2.70	0.24*	0.02	0.22*
Realistic	2.74	2.91	2.80	0.17*	0.07	0.11*
Time-based	2.52	2.67	2.65	0.15*	0.13*	0.02
Overall	13.00	14.26	13.65	1.26*	0.65*	0.61*

\* Scores that are significantly different from the initial scores at  $p < 0.05$  from the Wilcoxon signed-rank test.

Table 6 presents the differences in the students' self-evaluation of their S.M.A.R.T. scores between the initial answers and: (i) final answers for the same problem; and (ii) post-module answers for another problem. The differences between (i) and (ii) are also presented in the table. Although the results show a significant increase in the overall scores and most scores for the different SMART criteria in both the final answers and post-module answers, the results also show that most scores for the final answers are significantly higher than the post-module answers. Similar to the findings from section 4.1, students can consciously or subconsciously evaluate their work more highly toward the end of the exercise because they may believe that their performance should improve after the research activity. However, it was noteworthy to see that the students evaluated the final answers from the learning module higher than the answers they created afterward during the post-module activity. This may be

influenced by the fact that the students spent less time generating the outputs for the post-module answers, which may reduce the students' confidence in the quality of those answers. Also, this may suggest that the problem-based learning module's structured approach (i.e., (i) analyzing the problem (ii) identifying, locating, and evaluating further information for solving the problem; (iii) consulting with peers on approaches for solving the problem; (iv) making decisions on the final approach for solving the problem; and (v) reviewing own performance) led to responses that were perceived to be better solutions and policies to the selected problems. Therefore, these findings suggest that in addition to the benefits of gaining exposure to the types of people- and process-related challenges that students may expect to see in their careers when using BIM, another valuable aspect of this learning experience relates to the structured thought process that was incorporated in the activity.

### 4.3 The learning module's perceived impact on targeted skills

TABLE. 7: Students' feedback from the Likert-like scale questions.

The activity has enhanced my:	Semester (Fall 2017, n=55, Spring 2018, n=46)	Feedback			
		Strongly agree	Agree	Disagree	Strongly disagree
Problem-solving skills	Fall 2017	45.7%	39.1%	6.5%	8.7%
	Spring 2018	34.5%	49.1%	9.1%	7.3%
Analytical skills	Fall 2017	47.8%	37.0%	8.7%	6.5%
	Spring 2018	23.6%	61.8%	7.3%	7.3%
Ability to work as a team member	Fall 2017	45.7%	32.6%	10.9%	10.9%
	Spring 2018	29.1%	47.3%	16.4%	7.3%
Communication skills	Fall 2017	43.5%	34.8%	15.2%	6.5%
	Spring 2018	25.5%	50.9%	16.4%	7.3%

Table 7 presents the students' feedback on the activity through the Likert-scale questions in the post-module survey. The results show that students generally agree that the activity is valuable in enhancing their problem-solving, analytical, and communication skills, and ability to work as a team member. These results are encouraging especially because those skills and abilities are related to the non-technological skills required for resolving the common issues in BIM-based construction projects. In addition to the Likert-like scale questions, the students' feedback from the open-ended questions in the post-module survey indicates that students felt that the learning module made them think differently or from a new perspective. Several noteworthy comments were extracted from the open-ended responses to illustrate the types of specific feedback reported, including:

- "Makes you think outside the box, communicate with your team effectively."
- "Having to come up with more than one solution because it made me try to think outside the box."
- "The activity forces you to think about problems in a different way and use problem-solving skills to find solutions."

These findings generally align with problem-based learning in other, non-BIM, contexts. For example, previous research suggested that ill-structured problem statements could support the development of analytical and problem-solving skills because students would need to decide between multiple approaches to address the problem statement (Duch et al, 2001). This benefit of problem-based learning was directly echoed by some of the student responses to the open-ended questions. Furthermore, one of the students expressed that the learning module had made him or her try to communicate with the team effectively. This also aligns with prior research that suggests that problem-based learning can enhance communication skills because it involves individuals working cooperatively with other participants to generate the best outputs when solving a problem (Kenney, 2008).

The general findings aligning with prior problem-based learning research were largely expected as the previous works have already established those benefits. However, it is worth noting that the specific findings in this work demonstrate that the general learning benefits of problem-based learning can provide value specifically within a BIM context. This is evident in reviewing the responses generated by students. For example, the students' responses frequently involved BIM-specific strategies including: rescheduling coordination meetings; hiring a different modeling subcontractor; standardizing the modeling process between subcontractors; and integrating and streamlining model data. While the general thought processes required for generating these suggestions may be observable in other fields, it was noteworthy that they could also support specific BIM-related strategizing. Furthermore, the specific types of BIM planning skills observed align with those that are most targeted by current

industry practitioners (Rahman and Ayer, 2017, Rahman 2018). This provides further evidence of the value that problem-based learning may have for improving BIM education.

Despite the positive feedback, a minority of the students believed that the learning module was not valuable in enhancing their BIM planning skills. After reviewing the students' feedback in the open-ended questions, it became clear that these students felt that the activity was inappropriate because the problems did not have clear solutions. This sentiment is evident in several of the comments extracted from the open-ended responses, including:

- "Some of the problems didn't really have solutions. I was more of picking the lesser of two evils."
- "The problem seems open-ended without a clear solution."
- "My problem genuinely did not seem to have a solution."

While these students hesitated to report value to this type of activity, it is worth noting that the underlying concern they voiced is also one of the underlying motivations for leveraging problem-based learning. In other words, problem-based learning typically requires students to solve problems that can lead to multiple solutions (i.e., ill-structured). This is not generally the normal mode of education experienced by students where they are expected to arrive at an exact answer. However, this type of ill-structured problem is extremely likely to come up when students graduate and begin their professional careers in the construction industry, which highlights the importance of students becoming familiar with this type of problem in preparation for their future.

While there were some divergent opinions among students regarding the efficacy of this mode of learning, the majority of students indicated that they did believe there was value to this activity. When considering this finding in conjunction with the performance findings based on the S.M.A.R.T. rubric assessments, this seems to suggest that this type of learning activity can lead to educational gains in a single-session that effectively target the necessary people- and process-related skills required for effective BIM implementation.

## 5. CONCLUSION

This paper presents the learning impact of implementing a problem-based learning module that targets the skills required for addressing common, people- and process-related, issues in BIM-based construction projects. The major findings include:

- Problem-based learning enabled students to generate better outputs related to solving common issues in BIM-based construction projects.
- Students perceived improvements to their analytical and problem-solving, teamwork, and communications skills after completing the activity.
- Industry practitioners perceived improvements in the students' analytical and problem-solving, teamwork, and communication skills after completing the activity.
- The results demonstrate that the improvement in evaluations of student answers is a result of the structured thought process that is incorporated in problem-based learning's instructional design.

These findings suggest that problem-based learning can enhance the non-technological skills required for resolving the common issues in current BIM-based construction projects. Also, the structured thought process of problem-based learning's instructional design in generating outputs supports improved abilities to develop effective solutions to BIM challenges. The contributions of this paper are in providing educators with empirical data to guide their use of problem-based learning to support BIM education and also in documenting the assessment and implementation strategy used to support future educators in realizing the same types of benefits in their classrooms.

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