



Improving the Understanding of BIM Concepts Through a Flipped Learning Lab Environment: A Work in Progress

Mr. Christopher Monson, University of Washington

Christopher Monson, RA, is a doctoral student in the College of Built Environments at the University of Washington. He received his Bachelor of Architecture degree from the University of Minnesota and a Master of Architecture with Distinction from the Harvard University Graduate School of Design. Across a twenty-year academic career, he has taught design and construction studios, building detailing and assemblages, and architectural theory, and has been recognized institutionally and nationally for teaching. His research is focused on integrated AEC practice, studio-based learning, and design thinking. He is a licensed architect and a Leadership in Energy and Environmental Design (LEED) accredited professional.

Hoda - Homayouni, University of Washington

Hoda Homayouni is a senior Ph.D. student in the Built Environment program, University of Washington (UW). She is also a teaching associate in the Construction management department, at UW.

Dr. Carrie S Dossick, University of Washington

Dr. Dossick's main research interests focus on emerging collaboration methods and technologies such as Integrated Project Delivery (IPD) and Building Information Modeling (BIM). Current projects include (1) technology and collaboration strategies for green building design and construction, (2) global virtual teams, (3) applications of BIM and COBie in operations and (4) bringing BIM to the construction site via mobile. She has received funding from the National Science Foundation, U.S. Army, U.S. Department of Education, Mechanical Contractors Association of Western Washington, University of Washington Royalty Research Fund, University of Washington Capital Projects, the College of Built Environments' BE Lab and was awarded the College of Architecture and Urban Planning 2007 Dean's Development Fund.

Anne K Anderson, Washington State University

Anne Anderson is an Assistant Professor in the School of Design + Construction at Washington State University. Her research focuses on improving construction coordination efforts through the use of building information modeling (BIM) and emerging collaboration technologies.

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Abstract

This works-in-progress study explores the instructional design of a BIM software skills lab that uses problem solving in a flipped classroom instructional environment to enhance student learning of BIM concepts. The labs encourage student problem solving in an innovation we call *vignettes*: problems of limited range and scope that reduces ambiguity and reveals likely solution paths. By focusing student attention to certain aspects of the solution, the duality of abstraction and application of BIM concepts is made easier to learn. The study's initial findings suggest that the use of vignettes shows consistently modest improvement in students' understanding and transfer of BIM concepts. The study also shows where BIM instructional design can use the notions of clarifying BIM concepts, emphasizing formative assessment, and directed attention to provide benefits to student learning.

Introduction

Many disciplines in higher education are embracing the shift to more student-centered pedagogies like problem-based, experiential, and flipped learning. Architectural engineering, construction engineering, and construction management coursework design is following the same pattern. This is especially evident in the emerging areas of virtual design and construction (VDC) and building information modeling (BIM), where the normative lecture format may be of questionable effectiveness when students aren't able to actively gain direct experience with computer software. But given the time constraints of the traditional three-credit course, it is very difficult to cover virtual construction concepts and software skills such that learning outcomes are adequately realized for both. However, when concepts can be introduced and then reiterated through hands-on engagement of software skill-building used in solving specific construction problems, there may be an opportunity to bridge the gap between the learning outcomes of digital concepts and an introduction to software skills, doing both in a more time-efficient manner.

This paper explores the use of online software vignettes in an upper-level construction management course called Virtual Construction that introduces concepts and tools for BIM and VDC. The course is designed using a blended learning rotation model where students move through different learning environments during each class period: small-group discussions, online reading and assignments, and whole-class lectures and discussions. The innovation described and studied here is the software instruction component of the course called "Vignette Workshops"—a software skills lab that uses problem solving in a flipped classroom instructional environment. We use the term *vignette* to describe an instructional strategy where the problems are limited in range and scope so that ambiguity is reduced and likely solution paths revealed. The Vignette Workshops introduce software skills for SketchUp, Revit, Navisworks, and BIM 360 Glue. Each vignette problem is built around the application of key digital concept like "groups," "parametric," and "federated model" as they are used in major industry software packages and applied in construction practice.

The paper describes the design of the online vignettes and an ongoing work-in-progress study of their effectiveness in improving learning outcomes for essential digital concepts. The study used a pre- and post-design with anonymous online surveys assessing student's abilities to correctly define key concepts and apply them in new contexts. The study's initial findings suggest that the use of vignettes shows consistently modest improvement in students' understanding of BIM concepts. The study outcomes also show where BIM instructional designers can use the notions of *clarifying BIM concepts*, *emphasizing formative assessment*, and *directed attention* to provide benefits to student learning. The example provided by the vignette instructional designs and the evidence of their pedagogic effectiveness offers architectural engineering, construction engineering, and construction management educators new methods by which software skills might be incorporated into introductory BIM coursework.

Literature Review

BIM Concepts and Instruction. It is largely accepted that the burgeoning use of building information modeling in industry means that BIM has become a necessary content area for architectural engineering and construction management education.^{1, 2, 3, 4, 5} However, fully incorporating BIM instruction across design and construction curricula has proven difficult.^{6, 7} This problem is a result of both the challenge of the new technology as well as the complexity of teaching it. First, Wang and Leite⁸ note that BIM requires an understanding of construction logic and process as well as the collaborative practices of construction project management, both of which are beyond the simple mastery of software. Secondly, Kymmell⁹ and Nederveen et al.¹⁰ show how the introduction of BIM is often confusing because it is dependent upon abstract modelling concepts that explain relationships between geometry and data, and that these concepts have to be understood to learn what the software does and how it operates. Sacks and Barak³ clearly connect the necessary instructional relationships between the conceptual understanding of BIM and software skills in this way:

A good grounding in the principles of BIM, together with hands-on experience in one tool, will enable students to take up any one of a variety of other tools with minimal learning curve because they have a good grasp of the fundamental concepts. (p. 33)

Studies of learning and cognition support the connection between concept learning and the way knowledge is transferred from one problem domain to another. It is significant to note that educational researchers see the students' understanding of the underlying principles as the key dimension for applying learning to new problems. Bransford et al.¹¹ show that this is a characteristic of "expert" knowledge and argue that "the fact that expert's knowledge is organized around important ideas or concepts suggests that curricula should be organized in ways that lead to conceptual understanding" (p. 42). This conceptual learning allows students to represent their knowledge through abstractions that can connect the disparate components of new problems. Druckman and Bjork¹² say that this type of analogical learning transfer "leads to the induction of general schema for the solved problems that can be applied to subsequent problems" (p. 43). Where conceptual learning supports the transfer of knowledge to new contexts, these requirements to translate construction knowledge through the functionalities of computer

software suggest that building BIM knowledge and application upon its essential concepts is critical to BIM instructional design.

Blended/Flipped Learning and Vignettes. Garrison and Kanuka¹³ define blended learning as “the thoughtful integration of classroom face-to-face learning experiences with online learning experiences” (p. 96). Staker and Horn’s¹⁴ taxonomy of instructional contexts more specifically characterize blended learning through a number of models. Their “rotational model” is where “students rotate ... between learning modalities, at least one of which is online learning” (p. 8). The blended rotational model best describes the overall instructional design of the course studied in this paper, Virtual Construction, as it incorporates multiple online activities inside and outside of class with traditional in-class lectures and small group work. Among the variations of the rotational blended learning model is the well-known flipped classroom. The flipped classroom is an instructional environment where students use instructional media and online technology to learn course content outside of class time so that class time can be used instead for the application of concepts and learning activities—like problem solving and mentoring.¹⁵ Studies of flipped classroom applications in engineering classes suggest modest successes in terms of learning outcomes.¹⁶ Given the significant scope of work to completely redesign a course for flipped delivery, some scholars have pointed out that not all elements of a course need to be flipped to enjoy potential learning benefits.^{17, 18} This idea of flipping a particular part of a course applies to the instructional design evolution of the software skills lab component of Virtual Construction.

Each of the flipped labs in the course were designed to be limited in such a way that certain concepts could be explored more fully to produce better learning outcomes. We use the term “vignette” to describe the instructional design of these lab exercises: a multivariate problem given to students that is limited in its content and scope so that particular learning outcomes can be focused on and achieved. In a vignette, the problem is constrained by providing answers to specific aspects of the problem to negate their effect on the final solution, or by providing limits to the problem range so that ambiguity is reduced and likely solution paths revealed.

Designing the Vignette Workshops

As BIM uses and practices emerged over the past decade, architecture, construction and engineering programs began to introduce these software tools and business practices into coursework. While some curricula integrated BIM modules into existing courses, others created stand-alone BIM courses.² Here at the University of Washington, we chose to develop a stand-alone elective course entitled Virtual Construction. This class, taught in the Construction Management department, was designed as an elective course in an undergraduate construction curriculum. Students from other AEC disciplines frequently take the course, as do graduate students in construction, architecture, and the College’s interdisciplinary PhD program. The course was intended to cover the basics of BIM for uses in managing the construction process and facilitating collaboration among project participants, to introduce BIM and VDC software applications and their concepts, and to introduce students to the new practices emerging in the industry. The three-credit class met once a week for ten weeks matching the size of other courses in the program.

Through the five-year history of the course, its instructional design and learning outcomes have evolved. From the beginning in 2009, our design of this class included a split between lecture and lab components. The lecture portion of the class focused on BIM uses and practices such as visualization, coordination, 4D modeling and model-based estimating. The lab portion of the class focused on software concepts and skill building. Given that there was an extensive breadth of software to cover and only seven sessions in which to accomplish it due to academic year schedule conflicts, we developed one-to-three week "modules" that introduced students to SketchUp, Revit, Navisworks and BIM 360 Glue and highlighted key concepts represented in each. These concepts included ideas like surface versus solid modeling, object-oriented database structure, parametrics, and object sets. The course was taught in a computing classroom where each student had a desktop computer.

The first version of the lab portion of this course was tutorial-based BIM instruction where we introduced the software through in-class tutorials and then had the students work through modeling exercises as homework (Table 1).

Table 1. Original course design: BIM lecture topics, in-class tutorials, and homework.

Lecture Topic	Homework Assignment
Introduction: BIM, VDC	
Sketch-up Tutorial	Sketch-up Model
Revit 1 Tutorial	Revit Shared Layout
Revit 2 Tutorial	
Revit Modeling Work Session	Mid-Term 3D Model
Navisworks 1 Tutorial	
Navisworks 2 Tutorial: Clash Detection	Navisworks Consolidated Model
Navisworks 3 Tutorial: 4D Modeling	
4D Modeling Work Session	Final 3D/4D Model

The challenges we had with this instructional design revolved around the sequence of in-class software tutorials followed up by homework assignments applying the newly introduced software skills. There was a general sense that the class tutorials were unfulfilling. The homework was characterized by students “getting stuck” and frustrated. Instructors felt that walking through tutorials in class was slow, frustrating, and boring. We did not feel like we were adding to student knowledge in a significant way, and the in-class tutorials were not leveraging faculty's conceptual knowledge to help students learn as they spent the class showing software workflow. During the in-class tutorials, most of the students were either ahead and waiting or behind and lost. While instructors were busy helping individual students troubleshoot their use of the software, others were waiting for the instructor to keep going with the tutorial. The instructors made some attempts to introduce BIM concepts before beginning the tutorials, but

these concepts often were lost in the busy work of figuring out what button to click next in the tutorial sequence.

Seeing that the sequence of tutorials and homework was proving to be problematic, the “flip the classroom” movement offered a potential to improve the instructional design of the lab portion of the course. The flip the classroom philosophy has students watch lectures at home and then do active exercises during class time where faculty expertise can be leveraged to help guide students through problems or offer reflective critique of their work in progress. This instructional method captured our attention as a means of improving the BIM labs and moving away from the in-class tutorial-based lab sessions. We would flip the labs: have the students do the tutorials before lab and then have a hands-on workshop in the lab where they would work through the exercises and where faculty would then be available to answer questions and focus on illustrating BIM concepts. The first version of the flipped labs was developed and taught in 2012. We called the new flipped labs “Vignette Workshops.” In a vignette, the problem is constrained by providing limits to the problem range so that ambiguity is reduced and likely solution paths revealed. By focusing student attention to certain aspects of problem solution, the duality of abstraction and application of BIM concepts is made easier to learn. The vignettes were designed around BIM concepts introduced through class lectures and supported by the flipped classroom tutorial work that students completed at home before each lab (Table 2):

Table 2. Reformulated course design: Vignette workshop schedule.

Software	Lecture concepts	In-class vignette exercises
SketchUp	Introduction to BIM	Importing the site plan; Grouping the site plan; Modeling the building; Assigning colors and textures to the building; Using 3D warehouse to add components; using layers to hide the temporary objects.
Revit I: Basic Modeling Skills	Surface modeling; Groups vs Components	Importing/linking AutoCAD drawings; Creating levels; Modeling walls, floors, roofs, slab on grade, doors and windows; Defining rooms; Hiding elements in views; Using massing and site families; 3D views and rendering
Revit II: Quantity Take Off (QTO) and Layout Settings	3D Parametric Modeling	Creating rooms and room tags; Creating room schedules; Adding color schemes to floor layouts; Creating material take off and cost estimate for doors; Observing the connection between plan views and cost estimates; Managing sheet layouts.
Navisworks I: Quantity Take Off	Creation of Sets	Settings for allowing Navisworks to get updates from Revit; Organizing model elements under search sets; Performing QTO for all items; Creating resource catalog and attaching it to items; Performing virtual take off; Using Markup tools; Exporting the workbook; Applying changes within Revit; performing change analysis within Navisworks

Navisworks II: Clash Detection	3D visualization	Appending Revit files; Performing hard clash detection; Grouping the clashes; Distinguishing between modeling errors and valid clashes; Associating viewpoints with each group; Creating a report; Resolving clashes within Revit; Observing the resolution within Navisworks.
Navisworks III: 4D Modeling	4D visualization	Adding schedule to Timeliner; Creating selection sets for 4D modeling; Changing colors and transparencies for better 4D visualization; Adding legend to the simulation; Creating the 4D simulation; Exporting the 4D model; Creating animation; Adding the animation to the simulation; Make adjustments to the animation.
BIM 360 Glue: Clash Detection	Clash Detection	Uploading models; Merging Models; using tools panel; Using navigation panel; Comments and Markups; Clash detection and notifying other users; Fixing the clashes in Revit.

Homework Tutorial 1: SketchUp

You can download SketchUp-Make for use on your personal computers from the following link:

<http://www.sketchup.com/download>

Read [Professor Deb's SketchUp pointers](#) and work through the tutorials below. The videos total approximately 1-1/2 hours but allow yourself 2-3 hours to work through them. Be prepared to complete a SketchUp modeling assignment in class on Wednesday, Oct 1.

Use the SketchUp video tutorials to familiarize yourself with the basic tool sets.

Set 1: [New to SketchUp](#)

- SketchUp New Users (4 videos) (Length 45:15 total)
- SketchUp Toolbar Series: Selections, Components, Paint Bucket, Lines, Push Pull, Scale, Tape Measure, and Dimensioning (Length 30:23 total)

Set 2: [Familiar with SketchUp](#)

- Google SketchUp Techniques: Layers (Length 6:30)

Set 3: [Expert in Sketchup](#)

- SketchUp and CAD: Imports and Preparations (Length 8:56)

Figure 1. Homework tutorial assignment for SketchUp. View from Canvas.

Vignette Example: SketchUp

We use the SketchUp exercise from the course as an example of the instructional design of the vignette exercises and the sequence of activities required by students in the homework tutorials and in-class labs. The learning management system used to deliver the course components is

Canvas. Students logged on to the course in Canvas to access all lectures, tutorials, assignments, and assessment quizzes. The homework assignment for SketchUp instructed the students to download the software and then asked them to select from a number of available online tutorial videos provided by SketchUp that are based on a user's familiarity with the software (Figure 1). In this current version of the course lab design, there were no points offered for completing the tutorial and no assignment deliverable to submit. In this set of online videos, general tools and workflows in SketchUp are introduced. Since these particular videos are produced by SketchUp, the skills presented are not necessarily aligned with the exact tasks that will be required to complete the subsequent in-class vignette exercise.

In the next in-class lab period following the tutorial introduction to the tools in SketchUp, an instructor introduced a number of concepts that are central to the understanding of how SketchUp operates and which are common across other software packages. For SketchUp, these concepts include things like "layers," "components," and "groups." Students were then instructed to do the in-class modeling exercise available on Canvas (Figure 2). Using the logic of the term "vignette," this assignment asked students to work on a limited problem that pointed them to a drawing file to use as a base document and a particular website to locate other modeling objects.

In-class Exercise 1: SketchUp Model

This assignment explores the functionalities of SketchUp in the context of site planning. You will create a simple SketchUp model that practices and explores basic functionalities from the tutorials and supplemental materials. You will work with a .dwg flatwork base of a fictional "Research Building" site with 3D characteristics. Import the [Research Bldg Site Plan.dwg](#) file into SketchUp and use it as a Flatwork base for your SketchUp model.

In your 3D model include the building and surrounding parking areas. In the landscape, distinguish between asphalt and softscape. Include a building shell that represents the building on the site (no building interiors need to be modeled). The building has a glass curtain wall facing the interior courtyard and precast panel walls around the exterior with a built up flat roof and parapet walls.

Use the [3D Warehouse](#) to add objects (e.g. fencing, trucks, cars, people, trees) to your model.

(Backup file if .dwg import does not work: [Research Bldg Site Plan.skp](#))

Submit the completed assignment in Canvas at the end of class.

Figure 2. In-class vignette assignment for SketchUp. View from Canvas

By simplifying these parts of the exercise, students could engage the more specific questions of using SketchUp to create a building volume in its correct position and applying color and pattern tools to distinguish surface features. Again, the learning objectives in these vignettes were focused on building an understanding of concepts that undergird the software logic and that are commonly seen in other BIM applications and contexts. For the SketchUp vignette, the set of concepts was delineated as a grading rubric available to students on Canvas as part of the assignment explanation. Students worked on the vignette exercise in class and had instructors and peers available for questions and assistance. At the end of the lab time, students were required to submit their work through Canvas. As expected by an introductory assignment in software skills, the student work was generally basic and tended to follow the prescriptive outlines that structure the assignment (Figure 3). However, each vignette exercise attempted to

apply the software in ways that engage BIM concepts so that students could both improve their software skills as well as learn the larger conceptual logic that integrates software with broader BIM applications in industry.

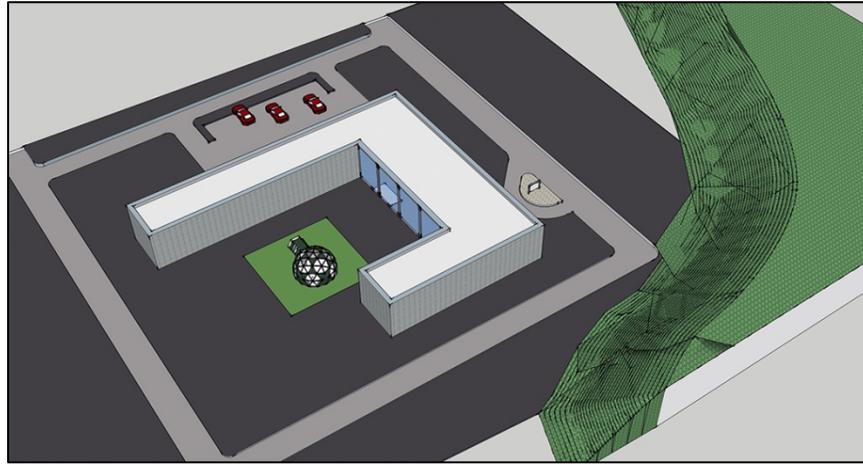


Figure 3. Example of student model for SketchUp in-class vignette exercise.

Research Design and Methodology

To evaluate the instructional design of the vignette exercises and their learning outcomes, we wanted to see if it was possible to measure formative improvement in student's understanding of BIM concepts before and after each vignette and summative assessments of learning BIM concepts. We also collected reflections about the instructional design of the vignettes at the end of the course. We devised a study with pre- and post-vignette surveys for each vignette to evaluate concept learning, as well as an end-of-term facilitated survey to provide collaborative student feedback on the pros and cons of the vignettes and the effectiveness of BIM concept learning. Two of the course instructors and a researcher with assessment and course design experience met weekly through the length of the term to discuss the vignette exercises, the concepts they were meant to teach, and to develop survey questions to measure learning outcomes. The study was applied to the fall 2014 offering of the Virtual Construction course. The study population was twenty upper-level undergraduate students.

For the pre- and post-vignette surveys, we developed questions that tested BIM concept understanding at the same level of sophistication that was used by the instructor introducing the concepts at the beginning of each vignette. Students were asked to voluntarily fill out a pre- and post- survey with these questions before and after the in-class vignette (Figure 4). Students completed this work individually and anonymously through Canvas. There were no points or other inducements provided to students for completion of these pre- and post- surveys. The survey questions followed the general pattern of 1) a multiple-choice question testing the ability of students to apply the concept to a given scenario, followed by 2) a short answer question asking student to explain their answer to the previous question, ending with 3) a five-point Likert scale question that asks the students to report as to how sure they were about their answer to the multiple-choice question. The multiple choice questions were constructed to assess how well

students could apply a particular concept in a new—but related—context. This methodology was an attempt to apply the notion of “analogical transfer” as presented in the learning and cognition literature.^{11, 12} We wanted to assess if there was evidence of learning through student abilities to transfer the understanding of a concept from one context to another context.

Question 1 pts

In a Revit model of an office building, there is a cost schedule for interior finishes (including room name, flooring, wall covering, doors, electrical and mechanical fit out). If the designer moves a wall 3 feet to make the office suite bigger, what attributes in the cost schedule will change?

- Area of floor
- Doors
- Room name
- Area of walls

Question 1 pts

Explain your answer above. Why did you select these item?

Question 1 pts

How sure are you of your answer to Question 1 above?

- Very unsure
- Somewhat unsure
- 50/50
- Somewhat sure
- Very sure

Figure 4. Example of pre-vignette survey for Revit II. View from Canvas.

For an end-of-course evaluation, we developed a survey tool with two fundamental questions: 1) “What course elements in this class helped you learn software concepts?” and 2) “How would you change the course elements so they worked better for learning software concepts?” The external researcher on our team who was not participating as an instructor in the course acted as a survey facilitator with students on the last meeting day of class. First, he asked the students to fill these forms individually and then had the students assemble into groups of three and asked them to discuss their responses and answer the same questions again as a group. He observed the

discussions in each group and encouraged them to write down their ideas as they were emerging within the discussions.

Findings on Vignette Concept Learning

Data across six vignette surveys were assembled. In terms of a quantitative assessment, percentages of correct and incorrect answers were calculated. To analyze the pre- and post-vignette survey results, we used the first two questions to determine the number of students that had a good, fair, and weak understanding of the concepts. A descriptive summary of correct answers and level of concept understanding are shown before and after the vignette in Table 3. As shown in the table, student understanding of BIM concepts explored in the vignette modestly increased in each of the six lab exercises.

Table 3. Pre- and post-vignette score data.

Software	Concept	Pre-vignette Scores *			Post-vignette Scores *				
		% correct	Understanding			% correct	Understanding		
Good	Fair		Weak	Good	Fair		Weak		
Sketch Up	Groups vs Components	47%	9	7	3	55%	5	4	0
Revit I	Parametric Modeling	36%	5	2	7	40%	6	6	3
Revit II	Parametric Modeling & QTO	68%	13	4	3	83%	15	2	1
Navisworks I	Creation of Sets	38%	6	6	4	42%	5	6	1
Navisworks II	3D Visualization	59%	10	7	0	75%	3	1	0
Navisworks III	4D Visualization	16%	1	3	2	33%	2	2	2

** Pre- and post-vignette totals not always equal due to voluntary responses*

Statistical analysis through two-group t-tests showed no significant differences between any of the paired vignette survey data sets at $p < .05$. This is not entirely unexpected given the limitations of question construction and the small self-selected sample size that varied pre and post test. It is important to note that we found the construction of appropriate questions for the pre- and post-vignette tests to be quite challenging, and we recognized in a number of instances where question wording and the potential ambiguity of multiple-choice answers appeared to have been confusing to students. However, we think that the assessment does reflect a consistently modest improvement in the percentage of correct answers across all six vignettes. While this result could be influenced by problems with test format familiarity, we find that this potential actually promotes the issue of learning transfer. The pre- and post-vignette questions involved the same BIM concept but viewed through different contexts. In other words, the data may be

showing increases in performance due to how the questions demonstrate learning transfer of BIM concepts in different contexts to students. Since learning transfer is a desirable trait for concept learning, this test validity issue, if it exists, is not fundamentally problematic.

In terms of qualitative assessment of student's written explanations of their answers, we found the same modest improvement in the pre- and post-vignette questions that was seen in the quantitative analysis of scores. Students appeared to answer questions "less wrong" in the post-vignette surveys than they did in the pre-vignette surveys. For example, in the pre-test for the SketchUp vignette, answers to the question "Explain the difference between groups and components" included "Groups are a number of shapes or objects which have been joined as one object. Components are individual objects" and "Groups are multiple components," both of which demonstrate that the students did not have a clear understanding of the concepts of groups or components. In the following post-test, students did not make those same mistakes (0 out of 11 wrong answers). The same thing was seen in the Revit II vignette. There were no wrong answers in the explanations in the post-vignette survey (0 out of 16 wrong answers), although there were incomplete selections of the multiple choices that implied students still had problems applying the concepts. There were three (out of 19) wrong answers on the pre-vignette test question on what happens when a designer moves a Revit model wall three feet to make an office suite bigger. One student answered "Only the area of floor will change because the door will be moved 3 feet. The door, room type, and area of [w]all would remain the same because there was no change in dimensions for them." Here, the student missed the association between changes in floor plan area and changes in wall surface area. Not all student explanations were completely correct—sometimes they were qualified by comments like "I think this is what you do!"—but they were "less wrong" in ways that showed incremental awareness of how the concepts were applied.

End-of-class evaluation surveys also revealed some of the strength and weaknesses of the vignette workshops and concept learning. While the students expressed that in-class lectures and assignments helped them understand BIM concepts, there were also concerns about the breadth of materials they learned as opposed to the depth of the knowledge they gained. The students suggested working with fewer software tools—eliminating SketchUp, for instance—and replacing online tutorials with more engaging tutorials customized for the course. This could involve a small modeling project for the course content that was created while students were viewing the videos. Requiring students to submit this project before lab would give students more incentive to do the tutorials. Such projects would also offer formative feedback to instructors about the kind of content and concept elements that the students need more help with during the vignette activities. This kind of feedback could focus instructor efforts in their interactions with students during the labs.

Students generally felt that there was too much emphasis on concepts in the course. This is an interesting response in that it represents the perennial struggle between the skills students say they want out of practical coursework and the learning processes that would allow them the capacity to access knowledge and reapply it in new contexts. The education literature shows us how important concept learning is to the development of expert knowledge. The student opinion about "too much emphasis on concepts" could be changed if these issues of learning theory were regularly brought up with students and demonstrated across the work of the term. For instance, it may be that the moments where concepts make direct connections to applications during lab

activities need to be pointed out more frequently and energetically. When students see how concepts help them organize their approach and support how they think about problems, they may be more likely to accept the value of learning concepts as necessary abstractions, as opposed to rote memorization of software workflow. We also see that students occasionally use this type of critique of concepts as a defense against the difficulty of learning that depends on analytical and synthetic thinking. This effect is sometimes increased in instructional environments where students are expected to take an active role in their learning. Because the flipped-classroom vignettes allow more comprehensive student-instructor interaction, we have seen how students come to value and appreciate the opportunity to work in a more productive and learner-centered environment—even when that environment places more expectations on their performance.

Suggestions for Instructional Development of the Vignettes and Labs

Our next efforts to improve the curriculum will focus on three main themes: clarifying BIM concepts, emphasizing formative learning assessments, and using directed attention.

From the work of this study, one of the suggestions for instructional development of BIM coursework involves *clarifying BIM concepts*. At various moments in the development of the vignettes and the research study itself, we found that the identification, definition, and application of BIM concepts was occasionally a ground of ambiguity and variance. For instance, for the post-vignette survey on 3D visualization, we asked “After running a clash detection, which of these tools can help the MEP coordinator make the view of a clash more legible?” with the choices being “change colors and transparency,” “hide geometry,” “create selection sets,” and “use object parameters.” While the two later options are not typically used for making the clash views more legible, they can theoretically be used to do so as one student explained: “The [creation of selection sets] by hiding the unnecessary information allows the view to be more clear and not obstructed.” Pushed further, the use of object parameters can also be used to convey more information like size and the exact coordination of the objects. While we were usually able to determine if a student had learned the concept well enough from their explanation, this example demonstrates the more slippery problem of the clarity of concepts in general. Within our team of expert instructors and researchers, the conversations about these concept ambiguities during the design of the vignette test questions were often provocative and fruitful. However, such uncertainty is not always an appropriate or useful point from which to engage construction concepts and software skills with novices. Expecting conceptual clarity across a new disciplinary phenomenon like BIM isn’t necessarily realistic. However, it may be important for the instructional design of BIM courses to make sure that those concepts with multiple or varying definitions are clearly defined and consistently applied. It may also be beneficial to students for instructors to introduce the fact that some concepts are evolving, and this is a natural and constructive condition in all realms of practical knowledge.

From the process of studying this course and analyzing its learning outcome data, another suggestion for improving the instructional design of BIM coursework is *emphasizing formative learning assessment*. Formative assessment is the process of student evaluation used to inform teaching practices rather than to assign grades¹⁹ (p. 25). Formative assessment also works as a tool for learning because of how it embeds periodic student reflection on course content. It may be that the effect of consistent improvement in vignette test scores across our lab designs was a

result of how the question process focused student attention on the processes of knowledge transfer. In other words, the short vignette quizzes contextualized how concepts move from one problem to another, and therefore helped students learn how to answer learning transfer questions for BIM concepts. While such an effect was not our intention, all research studies of classroom learning have the opportunity to act as formative assessment tools for instruction if considered as part of the opportunity represented by the study. Our experiences here may suggest that embedding formative assessment is a potential strategy for improving the learning outcomes of BIM concepts by focusing student attention on that concept through immediate application and transfer. More research on this proposition is necessary.

From the reflection on why certain vignettes appeared to offer better concept learning than others, another suggestion for improvements to BIM concept instructional design is something that might be called *directed attention*. Among BIM's unique characteristics are the connections it makes between geometry and data. Software used for BIM applications frequently uses that connection in its computational architecture in ways that allow users to see it in action. When analyzing the relatively strong achievement of the Revit II vignette, we recognized that the design of that particular exercise included a "directed attention" aspect as part of the vignette activity. The Revit II vignette was based in the BIM concept of parametric modeling and focused on applying quantity take off (QTO) and cost estimating capacities of the software. In the vignette, students were asked to apply a color scheme to their floor plan based on the room types. After producing a QTO of their plan, we asked them to change a room function within the QTO schedule in Revit and observe the subsequent change in their floor plan. We also asked students to change a door type from the plan view and observe the change is caused on the door schedule. In both instances, Revit makes instantaneous changes to drawings and schedules and changes can be made from either interface. As the students performed better on this particular vignette than any other, it may suggest that this simple directed attention exercise pointing out the concept relationships of geometry to data in BIM made a measurable difference in student learning.

Notable limitations of this study include the construction of pre- and post-vignette questions, testing effects on outcomes, the inconsistency of instructor and peer interactions with students in the lab environment, and the small sample size. During the study, the research team quickly realized the difficulty of constructing balanced pre- and post-questions that could adequately measure the application of a BIM concept from one context to another. Further study of this course will require additional expertise in survey question design. We also saw how variations in instructional contact with students during vignette workshop labs might affect general student learning. This is a fundamental problem with all active learning environments; it is impossible to guarantee the same level of interaction and learning outcomes with every student in every class period. However, the goal of such environments is not necessarily that all students achieve the same level of learning at the same time. Outcomes in student-centered learning environments are better measured across longer arcs of course content and activity. It may be that we see more significant improvement in BIM concept application and transfer in other aspects of the course that are not currently being measured.

From this study, we find other improvements to the design of this instructional environment that will be considered. Given the potential that formative feedback is itself increasing learning outcomes, it seems reasonable to consider the option of providing points for accomplishing the pre- and post-vignette surveys. Overall, there needs to be continued effort to integrate the BIM

content between concepts, the tutorials, and the vignette problems. Right now, the use of available online tutorials is a problem in that they are not necessarily focused on the tools or skills required to engage the subsequent vignette problems, nor are they consciously designed with any particular emphasis on BIM concepts. Customized online tutorials would be a significant advantage in meeting these objectives, though that idea increases faculty workload by several degrees of magnitude as they would need to produce video tutorial context as well as plan in-class activities. Since the software itself changes annually, video productions could not necessarily be reused each year.

In conclusion, we hope to have shown through our work-in-progress that there is much to be gained by experimenting with differing instructional design strategies to address BIM and VDC software learning. This seems especially valuable for the particular difficulties of understanding of BIM and construction software concepts and their transfer to different contexts. The example provided by the vignette instructional designs and the evidence of their pedagogic effectiveness discussed in this paper offers architectural engineering, construction engineering, and construction management educators new methods by which software skills might be incorporated into introductory BIM coursework.

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