EVALUATING THE EFFECTIVENESS OF DYNAMIC TRAFFIC SIMULATIONS: A CASE STUDY IN TRANSPORTATION ENGINEERING EDUCATION

By

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Abstract

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Development of learning tools is critical for improving engineering education and learning difficult engineering concepts. When faced with authentic engineering problems experts rely on transferable understandings of concepts while students are constrained to preconceptions which do not translate to all contexts. Representations are learning tools commonly used by students to help organize thoughts in a meaningful way. Good representations help the user by providing insight to a concept or problem through explicit cues. Researchers at the University of Idaho have put together structured activities involving animation representations of traffic simulations designed as part of the Mobile Signal Timing Training (MOST) for teaching traffic signal timing. In this study the effectiveness of these MOST animations was evaluated through a pre-post-comparative case study. Overall, the MOST animations were successful in improving students' understandings of timing parameters involved in actuated control at signalized intersections. More specifically, students understood the respective roles of minimum green time, passage time, and maximum green time in the signal timing process as well as the proper duration of the green indication. The change in understandings from pre-to-post interviews were linked to the MOST animations through observations and reflective surveys. Students also showed improved understandings of the

relationship between cycle length and delay, but this change could not be attributed to the MOST animations. Additionally, misconceptions and areas of conceptual difficulty were investigated through the inclusion of students from other universities enrolled in courses where the same concepts were presented using other methods. Students who were not extensively exposed to the MOST activities had difficulty understanding how the maximum green timer works as well as the purpose of the minimum green time. This indicates that animation representations are effective in improving students' understandings of concepts involving dynamic processes or reactions.

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INTRODUCTION

Purpose of the Study

The design process in the field of engineering often requires both iterations and ingenuity. In order to effectively design, an engineer must have the appropriate framework to apply relevant knowledge. It has come to the attention of educators and practitioners that many new graduates do not enter the field of engineering with an accurate understanding of concepts in their specialty, as seen through the results of concept inventories designed to measure conceptual understanding (Foundation Coalition, 2001). It is likely that this is partly due to context; when taking classes students are provided with knowledge in the form of tools such as equations and definitions that are not useful to the students because they have yet to be assimilated into the culture or field in which these tools are applied. Research in physics and mechanics show that students problem solve by either referring to their preconceptions or relying on tools that they cannot derive on their own (McDermott, 1984). Substantial efforts have been made in the area of engineering education in hopes of reforming classrooms at the college level to improve the quality of graduates as they enter the workforce.

The Federal Highway Administration (FHWA) is one example of industry investing in education through the Transportation Education Development Pilot Program (TEDPP). The goal of the TEDPP is to provide training for anyone who works in transportation (Federal Grants, 2011). Additional training at universities such as the University of Idaho (UI) involves the development of courses that incorporate teaching techniques other than the typical fifty minute lecture. These techniques include animations, short activities, the integration of software, field trips, and realistic design projects. Education research in the sciences suggests that many of these techniques could improve students' conceptual understandings of course material because they are interactive and the content is situated in a more applicable context.

Implementation of these new courses and curricula is a first step in reforming transportation engineering education. The crucial next step is an evaluation to determine how effective the modified curriculum actually is. Instructors may choose to adopt a teaching based on findings from education evaluation studies. In the absence of evaluation, instructors may assume students understand the content covered in a course. Comparing exam scores of students taking a class at different times can reveal some insight. However, these exam scores often do not reflect a student's conceptual understanding, but rather their ability to use equations or follow a procedure. A more thorough evaluation is vital in the development of new approaches for learning.

Researchers at UI have developed Mobile Signal Timing Training (MOST); a simulation environment for teaching traffic signal timing. A large effort has been put forth to produce animation representations for MOST. The MOST animations are simulations created in VISSIM (2010). They show a model intersection with a depiction of the controller status in a gray box. The development team for MOST has put together several activities incorporating these animations of simulations that are intended to illuminate one or more key concepts or relationships. These activities allow the learner to directly observe the effects of changing signal timing parameters on traffic at a signalized intersection through simulations. In these activities students work in pairs making observations, collecting data, and answering questions specific to the concepts being covered. A screenshot taken from one of the animations can be seen in Figure 1. This MOST animation was used in an activity where students relate the length of the detection zone to the duration of the green indication. The rectangles on the intersection approaches denote the detection zones. For this simulation, the passage time is set at zero which means the phase will change as soon as the detector on a phase is unoccupied. Phase 4 from the intersection on the right with the longer detection zone will terminate after the one on the left because it can detect vehicles that are farther back in the queue. Both phases terminate in a mechanism known as gap out.

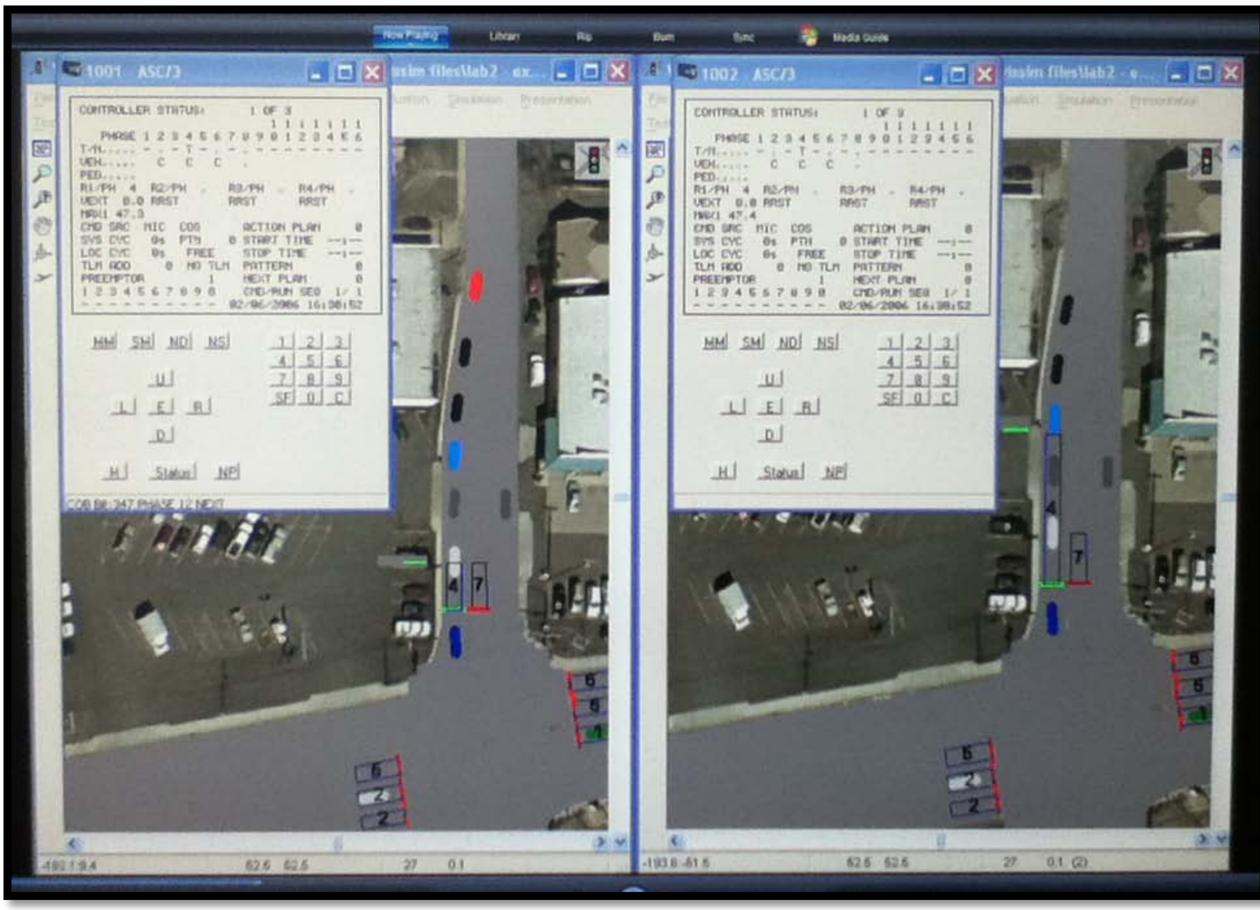

Figure 1. Screenshot of a MOST Animation

These activities should help students learn because they are interactive. Students work together at lab stations responding to animations. It has been shown that collaboration and discourse mediate learning better than constructive, active, or passive activities such as working through problems independently or taking notes during lecture (Chi, 2009). In addition, the extra dimension of time provided by the simulations can reveal insight that static representations portray implicitly, if at all. The purpose of this study is to evaluate the effectiveness of the MOST activities that involve animations. This was done by determining conceptual change from pre-to-post interviews of students who participated in the activities involving MOST animations and comparing their understandings with students from UI in a previous semester, Portland State University (PSU), and Oregon State University (OSU) who had minimal or no exposure to MOST animations.

Literature Review

Cognitive scientists suggest that people classify things into ontological categories (Slotta et al., 1995). Basic categories might include things, ideas, and processes. People then draw conclusions or proceed with constructive thought about a new topic based on how they have classified it. Any existing knowledge a person brings with them to a new learning environment is referred to as a preconception. Preconceptions have already been classified and can be referred to when learning new material. New knowledge is placed into seemingly relevant categories amongst existing knowledge. Sometimes a person's preconceptions do not transfer when applied to a new context which leads to a misclassification. These misclassifications are referred to as misconceptions and can lead people to inaccurate notions of ideas or processes involving that concept. For example, it was found that students in a physics class placed process-based concepts such as light, heat and electrical current into matter-based categories which deterred their problem solving abilities (Chi et al., 1994). Misconceptions have been defined in a variety of other ways from students' misinterpretations of scientific information (Vosnieadou, 1994) to mistakes that hinder learning (Smith et al., 1993). In time a person will ideally form a solid conceptual understanding of new material through a process known as conceptual change. People can then rely on their conceptual understanding when faced with a problem rather than preconceptions alone. In this study the use of the term *conceptual change* will refer to any development in a students' understanding of a concept.

The transition from reliance on preconceptions to conceptual understanding occurs during the acculturation process (Hestenes et al., 1992). To understand the acculturation process one must first think of an area of study as its own culture. Within each culture there exists common knowledge, concepts and processes which are all context dependent; the way in which these concepts are applied is unique or specific to this culture (Romney et al., 1986). It takes a member of the culture with embedded knowledge to know how to properly apply these things in practice (Brown et al., 1989). A student taking first year physics will be given knowledge in the form of equations, definitions and figures in the classroom and be expected to solve problems using these tools. The student, however, is not a part of the culture of physics and will not know how to properly apply this knowledge. They may be able to plug in numbers and get a correct answer for homework or a test but this does not reflect a complete understanding of the concepts (McDermott, 1984). Complex tasks, like those found in practice, simply cannot be mapped out in a series of steps; many problems will require more insight, or a conceptual understanding of the material, to be solved (Brown and Duguid, 1991).

Numerous tools exist to aid in developing conceptual understanding. Common tools include equations, charts, and pictures. All of these tools are known as representations and attempt to model a concept or relationship. Representations are often helpful in problem solving because people think visually, not in words (Larkin and Simon, 1987). They help bridge the gap between the problem and solution by arranging the complexity of thought in a meaningful way on paper through diagrams or pictures (Larkin and Simon, 1987). They do this by helping better define the problem. Novice problem solvers generally have a difficult time with this step because they have a limited number of experiences for reference and are therefore less likely to recognize the configuration of a given problem (Sweller, 1988). Effective representations tend to include some form of human activity because human cognition stems from action and will also have apparent distinctions or insights so that the user can gain an in-depth understanding of the problem quickly (Sobek, 2001). By drawing out a problem, new relationships such as spatial cues can be brought out and used as additional information in assessment (Chi, 2009).

The use of an animation as a model or representation is aesthetically appealing which attracts attention and keeps the user motivated (Tversky et al., 2002). They can make certain aspects of a system more obvious than a static display (Scaife and Rogers, 1996). Of course, dynamic models do have limitations. Applying newly acquired perceptions of a dynamic concept in a more static manner can be difficult (Kaiser et al., 1992). The question now is how do specific animations help students learn and why? The goal of this study is to determine students' conceptual change on traffic signals concepts and the effectiveness of the MOST animations on this change. This will be the first application of conceptual change framework to an evaluation of transportation engineering education.

There is a recognized need for additional visualization tools in traffic systems engineering to provide insight on effects of the timing parameters on system behavior (Brennan et al., 2011). Web-based simulations were developed at the University of Minnesota (UM) (Liao et al., 2009). Students can view simulations of their designs for immediate feedback on the quality of their work. These simulations cover several topics within transportation engineering including highway design and traffic engineering (Liao et al., 2006). Preliminary evaluations of these simulations were conducted using pre-post-surveys and quiz scores. This evaluation indicated that the simulations were effective in self-reported understandings of students (Zhu et al., 2011). However, it was noted that a comparative study with a better experimental design should be conducted to further evaluate the effectiveness of visual representations in transportation engineering (Zhu et al., 2011).

The MOST approach is focused on actuated control and includes animations of simulations. Students are guided through observation and discussion of the effects of each timing parameter. The MOST animations have traits in line with characteristics of good representations. Their dynamic nature is aesthetically appealing and attracts attention. The MOST animations are structured in activities where students interactively work through activities, controlling the animations and discussing their observations with peers. Students are guided through each simulation to discover how distinctions with each simulation change the way the intersection operates. Finally, the activities are brief in duration which keeps the students motivated. A summary of concepts related to signal timing can be found in Figure 2. This figure is intended to serve as a reference for those who are not familiar with this area of study.

The signal timing design for any intersection is unique because every intersection has a specific geometry and experiences some unique pattern of traffic. There are several issues to address in determining an appropriate timing plan for a signalized intersection. Producing signalized intersections that are both safe and efficient becomes an optimization task. Some key concepts to be considered deal with relationships among users, detectors, and controllers.

Efficiency is often measured in terms of queue clearance and delay where queue refers to the number vehicles stopped at a red indication and delay is the time in which they are stopped. The goal of a signalized intersection is to clear the queue at each phase while minimizing the average delay for all vehicles. In general, delay is reduced by minimizing the overall cycle length. However, if cycle length becomes too short delay can start to rise due to increased proportions of lost time from start up and all red times. An example of this would be a four way stop with a long queue. The overall cycle length here would only be a few seconds, but the average delay is extremely high.

Pre-timed systems allocate green time to different phases consistently with each consecutive cycle. However, traffic flow is stochastic and the green time adequate for one cycle might not be optimal for the next cycle. Intersections with traffic that varies throughout the day will benefit with a system that incorporates actuated control. In actuated control, the controller receives data from detectors to determine when the phase should change. Every time a vehicle is occupying a detector the controller receives a call for that detector. A call from a detector on a conflicting phase indicates that a car is in queue. The controller can also estimate headway based on calls received from the detector on the active phase. It estimates headway as the occupancy time plus the time a detector is unoccupied.

The controller makes decisions by bounding the green time in three ways using the minimum green time, vehicle extension time, and maximum green time. The minimum green time allows stopped vehicles time to get moving at the start of the phase. Once the minimum green time expires cars will ideally be approaching the saturation flowrate. At this point the vehicle extension time takes over. The vehicle extension time is based on the maximum allowable headway, detection zone length, and vehicle speed and is used to recognize when the gaps between vehicles becomes unreasonably large. A large gap indicates that the initial queue has been served. It times down when the detection zone is unoccupied and resets every time a vehicle enters the detection zone on the active phase. If the vehicle extension time reaches zero the phase terminates in a mechanism known as a gap out. Meanwhile, if a vehicle is detected on an opposing phase, the maximum green time will begin timing down. The maximum green timer ensures that no vehicle will have to wait longer than a specified amount of time. It is set at a value that will minimize delay for cars in queue at a conflicting phase while allowing the entire queue on the active phase to clear. If the maximum green time reaches zero, the phase will terminate in a mechanism known as a max out.

Figure 2. Signal Timing Concepts

The MOST animations were designed to illuminate the effects of changing each timing parameter on the overall efficiency of intersection operations. Table 1 shows how different concepts or relationships were depicted in each of the activities that were investigated in this paper. The concept in bold is the key concept for each respective activity. Note the letters in parenthesis below each concept. These letters will be used to denote which concepts were targeted in which questions later when discussing the interview protocol.

Table 1. Outcomes of MOST Activity

Activity → Concept ↓	**Relating the Length of the Detection Zone to the Duration of the Green Indication**	**Determining the Length of the Minimum Green Time**	**Understanding the Variation of Vehicle Headways in a Departing Queue**	**Relating Headway to Unoccupancy Time and Vehicle Extension Time**	**Determining the Effect of the Minor Street VET on Intersection Operations**	**Determining the Effect of the Max Green Time on Intersection Operations**
Duration of Green Indication (G)	**How does the length of the detection zone affect the time at which the phase in each case terminates.**	Observe how minimum green time can affect phase termination.	Determine the longest headway you would want to allow between vehicles before terminating a phase.	—	Discuss how the passage time setting on the minor street affects the duration of the green interval on the major street.	Determine how maximum green time affects phase termination.
Cycle Length and Delay (CL-D)	Determine whether or not the phase in each case is operating efficiently or not based on queue clearance and delay.	What are roles of passage time and min green timer in producing efficient intersections.	—	Determine the effect of VET on delay by recording when each phase terminates.	Discuss how the passage time setting on the minor street affects cycle length and delay.	Determine the effect of max green setting on queue clearance and delay.
Passage Time/Vehicle Extension Time (PT)	Set at zero for this simulation.	Determine the role of passage time in producing efficient operations.	**Determining a maximum allowable headway to help establish the passage time.**	**Determine how the length of the detection zone affects the setting for passage time.**	**Determine effect of minor street passage time on efficiency of major street and intersection operations.**	—
Minimum Green Time (min)	Set at zero for this simulation.	**When is min green time too long. How long should min green time be to get vehicles moving.**	—	—	—	—
Maximum Green Time (max)	—	—	—	—	—	**Understand effects of increasing max green time on intersection operations**

The MOST animations are appealing because they allow students to directly observe different relationships through well-structured activities that do not take up an extensive amount of class time. There are other ways to accomplish this in the classroom, one of which could be the integration of modeling software such as VISSIM (2010). However, software packages can be costly and there are multiple leading names to choose from. In addition, there is a steep learning curve and time in the classroom is limited. If effective, elements of the MOST approach to learning could be a more realistic alternative to the incorporation of simulation software.

Questions of the Study

A case study design approach was used for the evaluation of the MOST animations. The main questions of the study are as follows;

1. How and why are the MOST animations effective in improving student learning and overcoming areas of conceptual difficulty?
2. What misconceptions do students have related to the operation of traffic control systems?

METHODOLOGY

This study investigated the effectiveness of activities involving MOST animations on students' understanding of concepts related to signal timing. Pre and post interviews were conducted with students in a traffic systems design course at UI, referred to collectively as Case A from this point forward, to determine conceptual understandings before and after exposure to MOST animations. To address issues of internal validity relationships were established by linking changes in understandings to observations of students interacting with the concepts in class using the MOST animations and students' opinions on what means of concept presentation were most helpful in learning the concepts, a strategy commonly used in case studies (Yin, 2009). Relative effectiveness was determined through a comparison of post interview results from Case A to three additional cases referred to as cases B, C and D. Cases B, C and D included students from traffic systems design courses offered at UI, PSU, and OSU who had limited or no exposure to the MOST animations. Investigating cases B, C, and D also helped in addressing issues of external validity by defining the domain to which results could be generalized as outlined by Yin (2009). Additionally, this study provided insight on preconceptions and misconceptions students have regarding signal timing concepts across multiple cases. Figure 3 depicts the overall research design. It could be argued that a randomized trial is best when evaluating the effectiveness of some variable but this was not feasible in this scenario because extraneous variables such as class size and instructor could not be controlled (McREL and ECS, 2004).

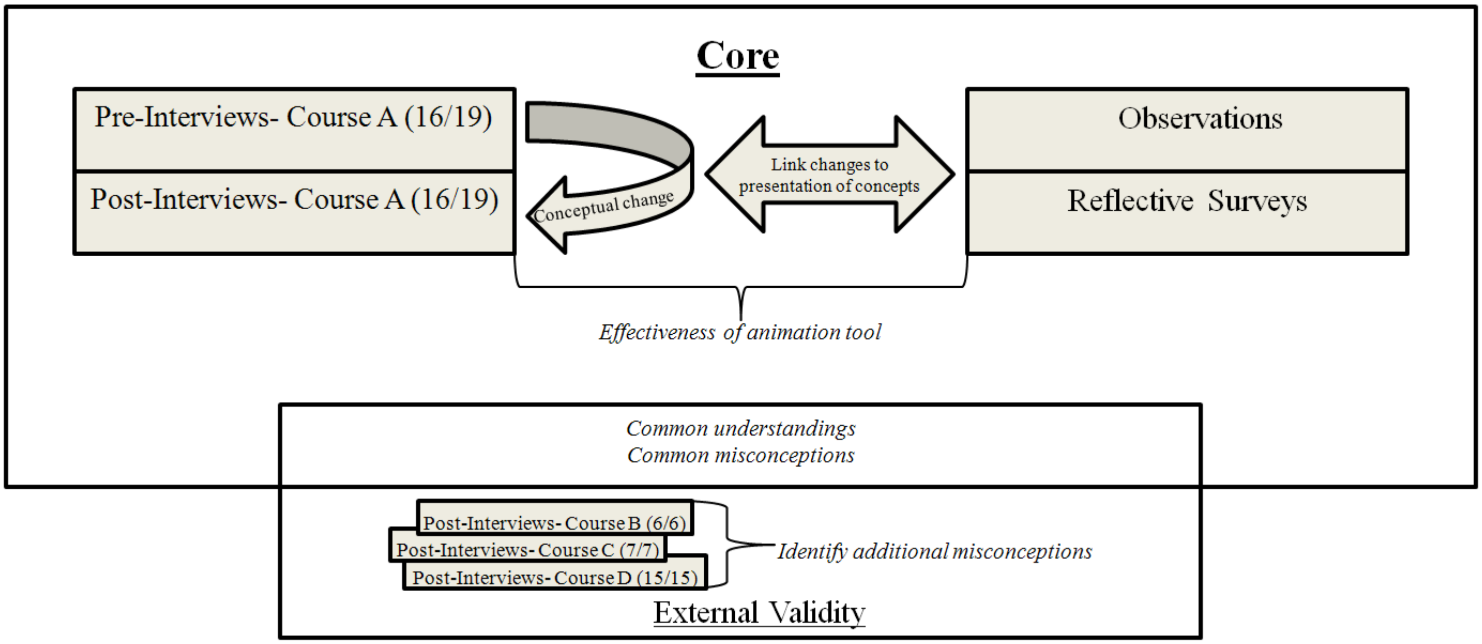

Figure 3. Research Design

Participant Selection

The MOST approach was first implemented at UI in a traffic systems design course. This course included field observations, group projects, and homework assignments in addition to the activities involving MOST animations as outlined previously in Table 1. Students who elected to take this course were junior or senior level civil engineering students. Sixteen of the nineteen students who enrolled agreed to participate in this study and they represent Case A. Participation in the study for Case A involved one-on-one pre and post interviews. Conceptual change was determined through these interviews. Interactions between students in Case A and the concepts presented to them were noted through observations. These students were also asked to complete a reflective survey at the culmination of the course where they shared their perceptions of what helped them in learning various concepts. Results from the observations and surveys were used to establish links between conceptual change and the course and ultimately make comments regarding the effectiveness of the MOST animations.

To determine relative effectiveness and address issues of external validity three additional cases were investigated. All additional cases included students who were in courses similar in content to that of Case A. Case B included students in a course that was taught at UI by the same instructor as Case A, but was offered in the previous semester. All six students who enrolled in this course participated in the study. This same course was taught jointly with a course at PSU. There was an instructor on location at PSU to proctor the class, but the instructor from UI provided assistance. UI is on a semester schedule and PSU is on a quarter schedule so only some units were taught collaboratively, one of which dealt with actuated control at signalized intersections, the area of interest for this study. Students from PSU are referred to as Case C. All seven students enrolled in this course participated in the study. Students from cases B and C had minimal experiences with the MOST animations which were in final development stages when these courses were being offered. Case D was composed of students from a course taught at OSU by a different instructor but covered the same material. All fifteen students who enrolled in this course participated in the study. Participation from students in cases B, C, and D involved one-on-one post interviews. The courses from all four cases covered the same content. Students from Case A were the only ones with extensive exposure to the MOST animations.

Interview Protocol

The nature of qualitative research is to provide detailed inquiries of a culture or group of people which are vital in the field of education (Marshall and Rossman, 2011). This was accomplished in part through interviews where participants provided detailed responses to open ended questions. During interviews students were encouraged to think out loud as much as possible which enabled them to express their thoughts openly. Interviews were designed to last around twenty minutes. The interview protocol was semi-structured; foundational questions were prepared and follow up questions were asked candidly based on the responses of the participants. The foundational questions were framed around major concepts or relationships that play a role in actuated control that the MOST simulations were intended to convey. Sample pre and post interview protocols can be seen in Table 2. Superscripts next to each question denote which concepts the questions were framed around and were defined previously in Table 1. Note that two of the post interview questions are indicated as videos. These videos are simulations and students were prompted to explain why the phases terminate when they do and explain why. Other questions had accompanying figures that were given to students as aids when responding. These questions are denoted in the table with “(figure)”.

As seen in Table 2, both the pre and post interview protocols followed the same structure and were framed around the same concepts. The foundational questions, however, were more complex in the post interview protocol. Pre interview questions needed to be worded differently than post questions because students did not have substantial experience with these concepts, but were necessary to characterize their preconceptions.

The pre interviews were conducted with students from Case A prior to their exposure to the MOST animations and served two main purposes. First they were used as a means to investigate any preconceptions students had coming into the course. These preconceptions could stem from life experiences on the road or content covered in the prerequisite introductory transportation engineering course. Also, results from the pre interviews would serve as a baseline when investigating conceptual change students from Case A underwent throughout the course.

The post interviews were conducted with students from all four cases and served two main purposes. First, post interview results from Case A were compared to pre interview results to determine conceptual change. This contributed to the evaluation of effectiveness of the MOST animations. Secondly, post interview results from Case B, Case C, and Case D provided an inquiry on students' levels of understanding after completing an upper level traffic signals course where traditional means of presenting concepts were employed. By comparing post interview results from Case A to the post interview results from the other three cases, relative effectiveness of the MOST animations could be determined. Additionally, common misconceptions or areas of conceptual difficulty could be identified.

Table 2. Sample Interview Protocols

PRE	POST
1. What is the purpose of a signalized intersection?	1. What does it mean to say you have actuated control?
2. How does the timing of a signalized intersection work? [PT, min, max]	2. What about an isolated intersection?
3. What would happen to delay if you replace a stop sign control with a traffic signal control at a signalized intersection? [CL-D]	3. When might actuated control at an isolated intersection be beneficial?
4. What should the time the green interval is displayed be based on?[G]	4. What is the purpose of the passage time? [PT]
5. Do pre-timed intersections do a good job achieving this and the overall goal of signalized intersections? [G]	5. Describe the relationship between passage time and maximum allowable headway.[PT]
6. How is actuated control an improvement?[G,PT,min,max]	6. What other variables affect passage time? [PT]
7. How does the controller decide when to terminate the phase? [PT,min,max]	7. How does detection zone length affect the setting for passage time? [PT]
8. When would actuated control be more beneficial than a pre-timed intersection?	8. (video1)
9. What do you know about detection at intersections? [PT]	9. If the passage time is set lower than optimal what will happen? [PT]
10. What types of detetion are there? [PT]	10. What if the passage time is set higher than optimal?[PT]
11. What is detection used for? [PT]	11. How will the passage time setting for a busy street differ from the passage time setting on a less busy street? [PT]
12. What is the purpose of the yellow time?	12. (video2)
13. What factors should be considered when determining the duration of the yellow indication?	13. What does it mean to say a phase terminates too early?[G]
14. How do the settings change for a really busy street compared to those for a less busy street?[PT,min,max]	14. What about a phase that extends too long? [G]
15. What is the effect of long cycle lengths at a signalized intersection compared with a short cycle length? [CL-D]	15. If a phase terminates too early or extends too long, what solutions should be considered? [PT, min,max]
16. What does it mean to say a phase terminates too early? [G]	16. Describe the relationship between cycle length and delay.[CL-D]
17. What about a phase that extends too long? [G]	17. How do you determine optimum cycle length? [CL-D]
18. If a phase terminates too early or extends too long, what solutions should be considered?[PT,min,max]	18. What is the purpose of setting a minimum green time? [min]
19. Prepare a sketch of the relationship between cycle length and delay? [CL-D]	19. What problems, if any, occur if the initial queue does not clear? [G]
20. How do you determine optimum cycle length?[CL-D]	20. What are some indicators of inefficient intersection operations?
21. What problems, if any, occur if the initial queue does not clear? [G]	21. What would an intersection that is operating inefficiently look like?
22. What are some indicators of inefficient intersection operations?	22. How might you measure efficiency?
23. What would an intersection that is operating inefficiently look like?	23. Show the value of each timing parameter in the form of a chart for the given detector status. (figure)[PT, min, max]
24. How might you measure efficiency?	
25. At what point during the cycle will the queue length be at its maximum for a uniform arrival rate? (figure) [min]	

Observations

Observations of lab sessions in which students completed the activities involving MOST animations were conducted. Each lab session was three hours in length and the first two hours were spent on the MOST activities for the observed lab sessions. Diligent notes were taken during these observations to provide detailed accounts of how students interacted with the animations in the classroom. Interactions included observations of animations, data collection from the simulations, minor calculations using these data collections, and discussion of questions provided in the activity. Other aspects such as organization, logistics, and complications could be seen firsthand. This information is useful in linking conceptual change to the way in which information was presented to students. Since the purpose of the observations was to link observed conceptual change to presentation of concepts they were only conducted with Case A.

Reflective Surveys

At the culmination of the unit on actuated control, it was requested that students from Case A respond to a brief survey. This survey asked students to list the ways in which different concepts were presented to them and specify which ways they felt were most helpful for learning the concept for five different concepts. These concepts were chosen based on observed conceptual change from pre to post interviews with Case A. Results from the surveys were used to further support or contradict conclusions drawn from interviews and observations regarding the effectiveness of the MOST animations. Nine out of sixteen participants from Case A responded to the survey. As with observations, surveys were only given to students in Case A because this was the only case in which conceptual change was investigated.

Data Analysis

All interviews were audio recorded and transcribed. Data analysis was performed using qualitative data analysis software, Nvivo (2006). By importing interview transcriptions and other documents into Nvivo (2006), common themes and trends could more easily be identified in the data. This was accomplished by creating nodes to code the interview transcriptions. First, a node was created for each question. Within the node for each question, nodes were created to classify the way in which each student responded. The response nodes were established upon each student's final answer and the logic they used to arrive at their answer. Finally, within each response a node was created for each case. From this it could easily be seen how students from each case responded to each interview question and statements could be made about how students from each case understand each concept. Table 3 shows the levels of nodes pertaining to question eighteen on the post interview.

Table 3. Example of Coding Process

Q18: What is the purpose of setting a minimum green time?																**Levels of Nodes**
vehicle start-up				**driver expectations**				***pedestrians***				**clear initial queue**				
A	**B**	**C**	**D**	**A**	**B**	**C**	**D**	***A***	***B***	***C***	***D***	**A**	**B**	**C**	**D**	
9	**2**	**3**	**1**	**3**	**3**	**5**	**6**	***0***	***2***	***1***	***5***	**3**	**2**	**0**	**4**	**Sources**
56.3%	**33.3%**	**42.9%**	**6.7%**	**18.8%**	**50.0%**	**71.4%**	**40.0%**	***0.0%***	***33.3%***	***14.3%***	***33.3%***	**18.8%**	**33.3%**	**0.0%**	**26.7%**	
Statement: Students from Case B, Case C, and Case D think pedestrian crossing time should be considered when setting a minimum green time.																**Statement**

Conceptual change was determined for Case A through comparing pre and post interviews. As mentioned, interview questions were written to uncover how students thought about each concept. For any concept, there was at least one question from the pre and post interviews to be used for comparison. After determining the change in understanding for a concept, notes from observations and results from reflective surveys were used to determine if the change could be attributed to the MOST animations.

To investigate relative effectiveness of the MOST animations, comparisons were made across all of the cases. If students from all cases understood a concept, then it was determined that the MOST animations were no more effective for that particular concept than current methods used to present information to students. If students from Case A understood a concept more completely than students from the other three cases and previous analysis linked understanding of that concept to the MOST animations then it could be said that the animations were likely more effective than other teaching techniques for that concept.

Misconceptions or areas of difficulty could be identified if questions pertaining to a certain concept were answered incorrectly by several students, if questions were answered correctly but students did not follow an appropriate logic when arriving at a solution, or if students could answer a question about a certain concept correctly in one context, but not in another. An example of this can be seen in the coding process in Table 3 where students from cases B, C, and D listed pedestrian crossing time as factor to consider when determining minimum green.

RESULTS AND DISCUSSION

There were five main areas of conceptual change observed in this study. These concepts include the duration of the green indication, the relationship between cycle length and delay, passage time/vehicle extension time, minimum green time, and maximum green time. For each of these five concepts results are first presented for the Case A pre interviews. Next, results are presented for the Case A post interviews. Finally, interpretations are discussed using results from the reflective surveys along with notes on the ways in which these concepts were presented to students in class to establish causal links for conceptual change. Relative effectiveness is also discussed through a comparison of post interview results from Case A to the other three cases of students who were not exposed to the MOST animations.

Concept 1: Duration of Green Indication

Students who were exposed to the MOST animations were able to articulate the proper duration of the green indication more prevalently than students who were not exposed to MOST as shown in Figure 4.

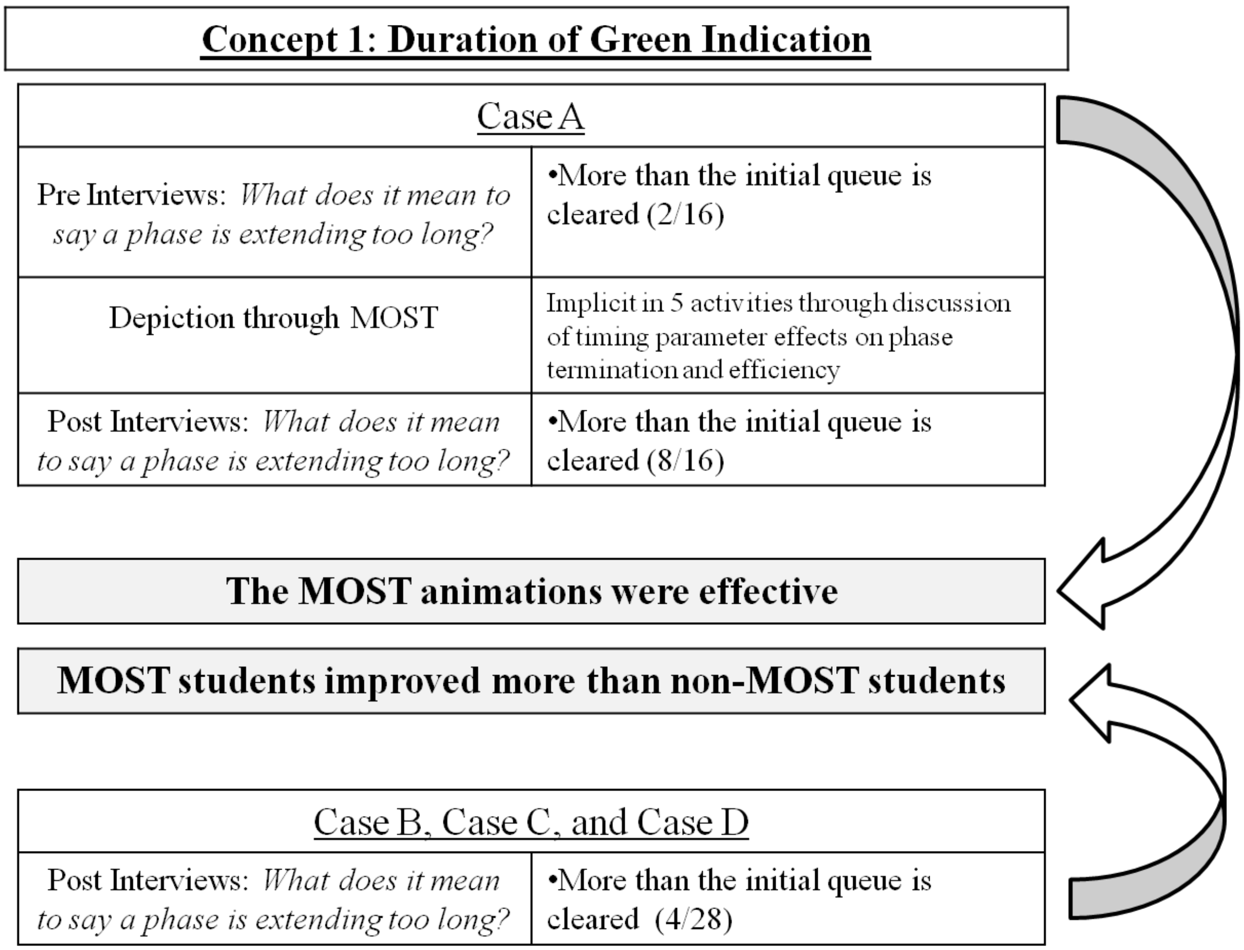

Figure 4. Results for Concept 1

Pre Interviews

In the pre interviews, students from Case A were asked to describe the optimal time in which the green interval should be displayed in question four. Six students correctly made reference to the initial queue. Eight other students also made reference to the queue in their answer, but indicated other portions that should be served in one cycle. For example, Student 31 suggested that a light should remain green until there are no cars approaching the intersection for that phase.

> ***Student 31:*** *Well, you're trying to serve the queue, so ideally you would have it be green in a certain direction until the queue's dissipated, and then until no more cars are coming, but that's not always possible…*

The remaining students responded in terms of traffic volumes in saying that green time should be allocated based on relative demand for each phase at an intersection. Students had another opportunity to express their understanding of optimal duration of green indication later in the interview. In question seventeen they were asked what it meant for a phase to extend too long. To this question, ten students articulated that a phase is too long if the green time is no longer being used, i.e., if there is no longer a demand on the active phase. This is what Student 39 expressed in their pre interview.

> ***Student 39:*** *There's just no traffic going through when it's green. So then, other vehicles are delayed, other approaches are building up their queues longer.*

This is true; however, there is another critical indicator. If vehicles are able to drive through an intersection without stopping while other vehicles are in queue on a conflicting approach then that green indication is serving more than the initial queue. Only two students brought up initial queue when answering this question.

Post Interviews

Students were once again asked what it meant for a phase to extend too long in question fourteen on the post interviews. This time, eight students referred to the initial queue in their response, as can be seen in the following quote from Student 39.

Student 39: *The queue has already been served, so it's just wasted green time when no one's going through the intersection, pretty much.*

Interviewer: *So it's green, but no cars are going through anymore?*

Student 39: *Yeah, or the gaps between the cars are too large.*

In their pre interview Student 39 did not add the extra detail regarding large gaps between cars when asked this same question, as discussed above. The students who did not reference the initial queue in their response listed unused green time or long delay as common indicators in their post interviews. These responses are also correct, but do not include one of the main signs of an over-extended green indication which would be servicing cars who were not part of the initial queue.

Interpretation

The results indicate that the way in which students thought about the appropriate duration of the green indication had changed by the end of the course. Students interacted with this concept in five of the MOST activities. Each activity focused on changing one timing parameter and observing the effects on phase termination and overall efficiency of intersection operations. Typical measures of efficiency that were used included number of cycle failures, queue lengths, and delay. Through discussion of efficiency while watching the animations students developed a sense of what an efficient intersection and an appropriate duration of green time look like in a simulation. In the reflective surveys students noted that the concept of proper duration of green indication was first presented in lecture, then observed through the MOST activities in lab. Students mentioned the lab activities aided in their understanding. Student 39, who showed an improvement in understanding from pre to post interview, believed that the activities provided a practical contextual example of the theory discussed in lecture.

> ***Student 39:*** *This was presented in lecture as well as a discovery activity. The lecture helped me understand the theory and the activity helped put the theory into a practical use.*

It can therefore be said that the MOST animations contributed to students learning about appropriate duration of the green indication. First, the activities were designed to illuminate related ideas or concepts. Second, it was observed that students were engaged during these lab activities. Third, during the interviews, conceptual change was observed and finally, students reflected that the activities were a helpful learning tool at the end of the course.

Further evidence of the effectiveness is present in the incorrect understandings of students from other cases. Only a total of 4 students from cases B, C, and D brought up the initial queue when responding to the question about phases that extend too long in post interview question fourteen. Students tended to limit their response to wasted green time as seen in the response from Student 12.

> ***Student 12:*** *If it was a green light and it seemed like no cars were coming, drivers on the other approaches would get impatient. It'd be like, "Why isn't it changing because there are no vehicles coming?"*

The students from Case A who were given the opportunity to observe effects of different timing parameters on the efficiency of intersection operations had several contextual examples to refer to when thinking about the appropriate time in which the green indication should be displayed for a phase when they responded to this question. Students' understandings regarding the proper duration of the green indication became more refined as they visually observed a variety of intersections operating through the MOST animations.

Concept 2: Cycle Length and Delay

Students from all cases understood the relationship between cycle length and delay as seen in Figure 5.

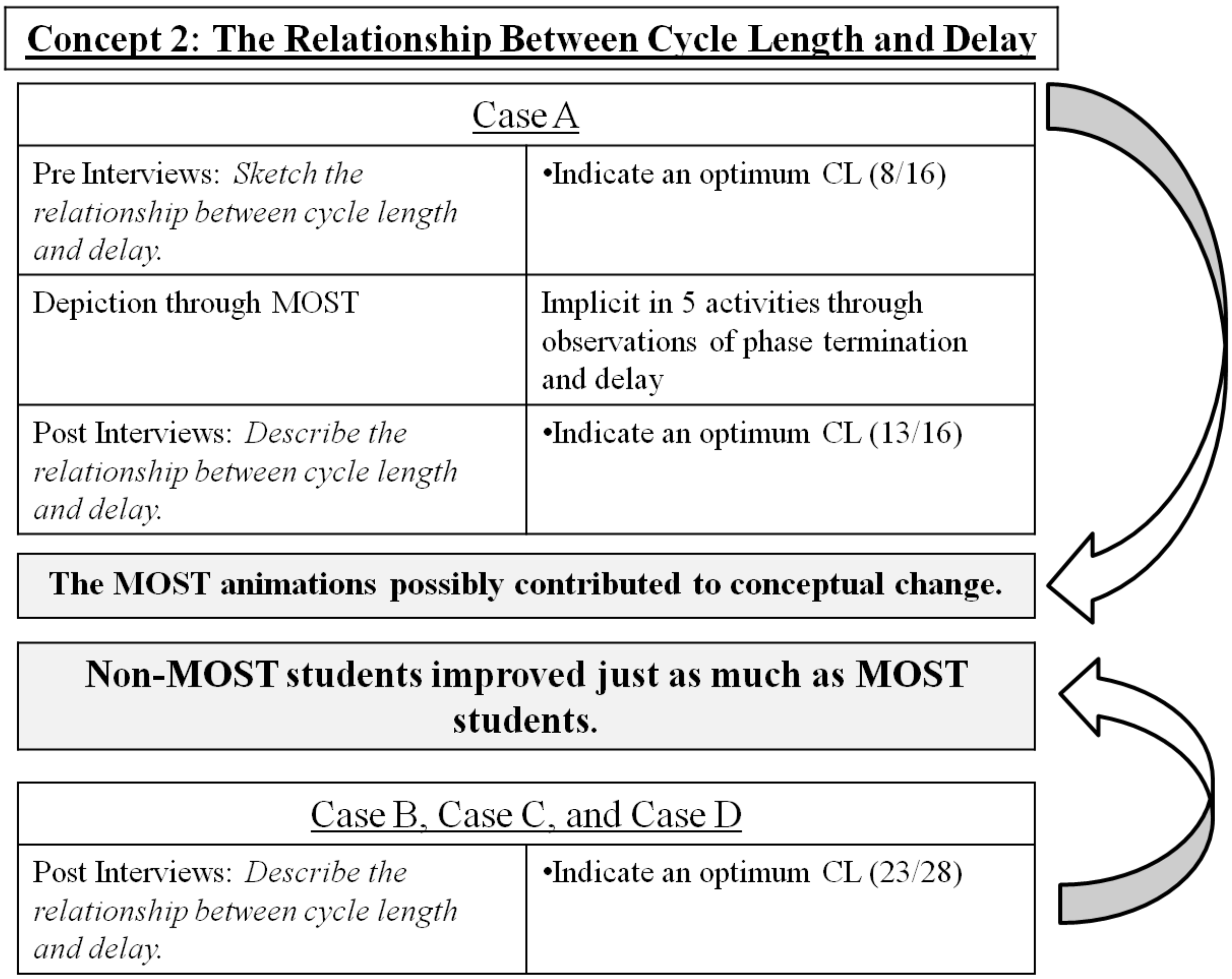

Figure 5. Results for Concept 2

Pre Interviews

In question nineteen of the pre interview students were asked to sketch the relationship between cycle length and delay. Six students drew a line showing a direct relationship between the two and explained that as cycle length increases the average delay at an intersection also increases. This is correct, but not complete. Too short of a cycle length can also increase delay as larger proportions of the cycle are wasted with yellow time, all red time, and vehicle start up time. This detail was only apparent in the sketches of eight students in the pre interviews. Of these eight students, four remembered the graphical appearance of the relationship from a previous course but were not able to explain the reasoning. This was the case for Student 37 who produced the sketch shown in Figure 6 and provided the following explanation.

> ***Student 37:*** *Let's see if I remember right. I think it actually goes something like that…and there is an ideal point in here somewhere you're supposed to aim for.*

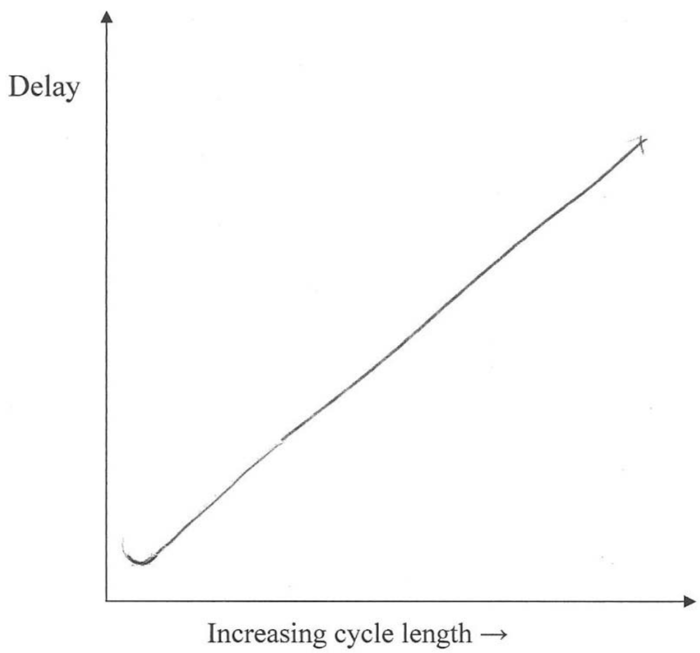

Figure 6. Sketch by Student 37

In this case the student recognized the existence of an increased delay with really short cycle lengths, but could not provide any further explanation.

Post Interviews

Question sixteen on the post interview protocol asked students to describe the relationship between cycle length and delay. Thirteen students described both extremities of the relationship and provided explanations. For example, Student37 who was previously lacking in insight could now provide a relevant contextual example to explain the relationship.

> ***Student 37:*** *The longer the cycle length, the longer the delay to a certain minimum point. At which point, if you have too small of a cycle, you get more delay… For example, like, a four-way stop sign would be the ultimate example of short cycle length. One vehicle served at a time.*

Other students provided similar contextual examples or gave a more insightful explanation than was provided in the pre interviews. The three students who did not describe the full relationship merely described the direct relationship between cycle length and delay.

Interpretation

This concept was implicitly present in five of the activities that had MOST animations. Five of the activities involved noting the delay for simulations of intersections that had varying settings for the different timing parameters. Through this they could see high delay as a product of both long and short cycle lengths. When asked what helped them learn this concept best, students expressed that the graphical representation in the textbook supplemented by a brief discussion in lecture was adequate for understanding the relationship between cycle length and delay. In comparing Case A with the other three cases it was found that twenty-three out of the twenty-eight students interviewed from other universities were also able to describe the complete relationship in post interview question sixteen. Reflective survey and interview results suggest that the MOST animations were as effective as other methods for student understanding of this concept. The relationship between cycle length and delay is not a particularly difficult concept for students to grasp and the animation is no more effective than other means of presenting information.

Concept 3: Passage Time/Vehicle Extension Time

Students who were exposed to MOST animations understood the concept of passage time. Students who were not exposed to MOST also understood passage time. These results are shown in Figure 7.

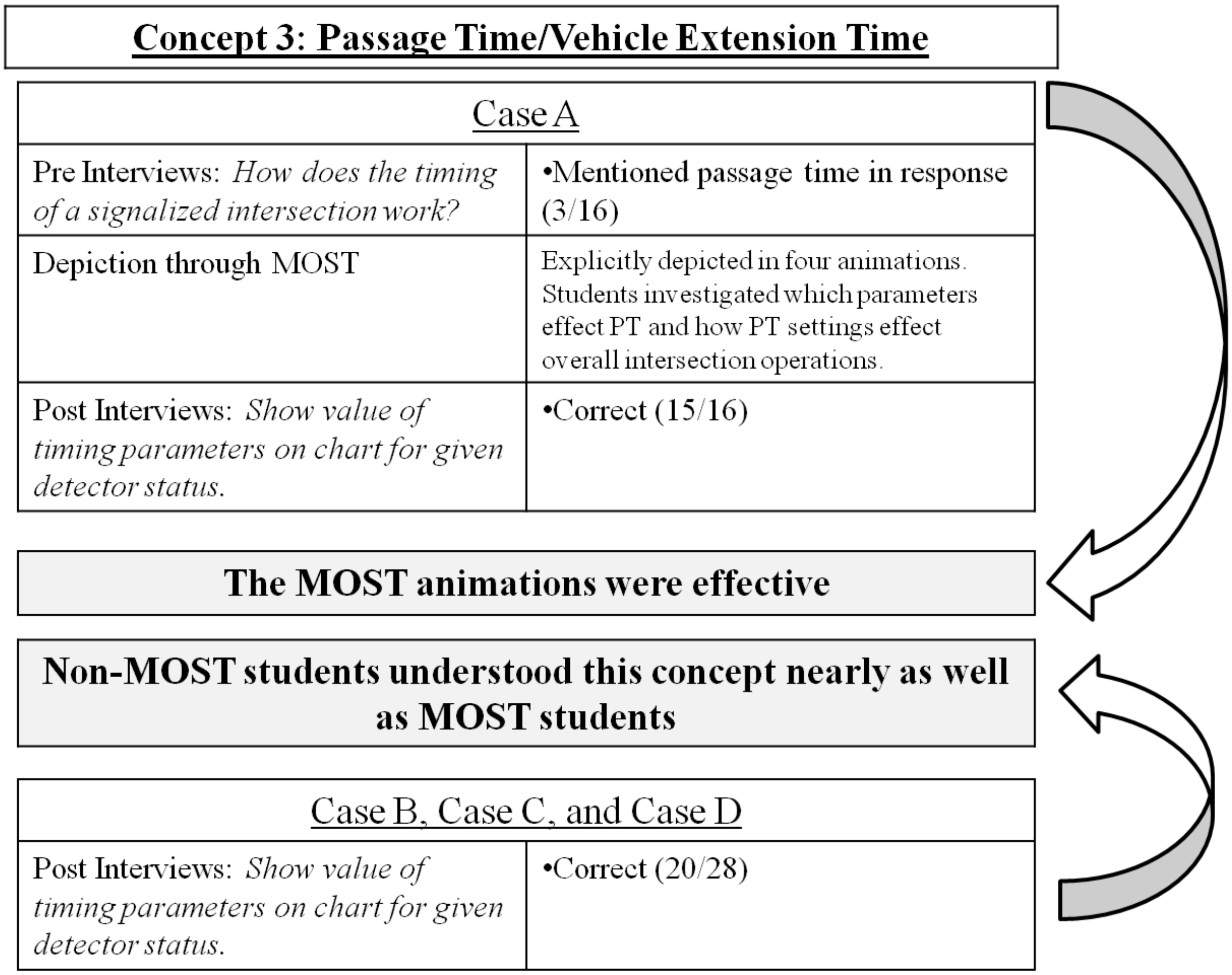

Figure 7. Results for Concept 3

Pre Interviews

Students in Case A were asked to explain how the timing of a signalized intersection works in pre interview question two. This question was intended to uncover the depth and breadth of the students' past experience with signalized intersections. All of the students brought up both pre-timed and actuated control. For pre-timed they explained that cycles are set with predetermined durations of green, yellow, red, and all red times. When explaining actuated control students stated that the systems are responsive to traffic. For many students this was the extent of insight provided. Three students identified passage time as one of the timing parameters used in the timing process but did not explain how it works.

Pre interview questions nine, ten, and eleven asked about detection at intersections. Detection is closely related to passage time in a couple of ways. Characteristics of the detection zone affect the setting for passage time and the controller receives data from the detectors to change the phases accordingly using the different timing parameters. When asked about different types of detection in question ten students could broadly identify two main forms, the video detection and some device under the roadway. However, they did not tend to know the extent of capabilities beyond detecting the presence of a vehicle when asked in question eleven. Many students openly admitted that they did not know if things such as vehicle speed, headway, or queue length could be determined from the detectors.

Post Interviews

Several questions were asked about passage time during the post interviews. When asked how the length of the detection zone affects the setting for passage time in post interview question seven, fifteen students described the inverse relationship in detail. Student 33 explained that longer detection zones need shorter passage times because they remain occupied longer than short detection zones.

> ***Student 33:*** *Yeah the longer the detection zone, the more likely that you will have the call activated, just because you know, if there's two cars and the detection zone is really small, there's going to be unoccupied for a long time, but if the detection zone encompasses both*

the cars at the same time, it's going to stay active, you know, this guy leaves, this guy's already in, I mean it's going to never think that there's a gap. So because of that, then the passage time can be a lot smaller.

Other students gave different explanations that were also correct. Students were asked to explain what happens when the passage time is set higher than optimal in question ten. All sixteen students noted that the likelihood of a phase maxing out increases when the passage time is set high. Nine of these students also mentioned that the average delay would increase for the intersection and there would be more wasted green time. Later in the interview in question fifteen students were asked about possible solutions for scenarios when a phase is terminating too early or extending too long. Twelve students described how the passage time setting could be adjusted for one or both problems. Finally, question twenty-three asked students to graphically show the value of each timing parameter for the given detector status. Fifteen students properly showed the passage timer counting down whenever a call was dropped on the active phase and resetting whenever a new call was placed.

Interpretations

At the start of the semester only three students mentioned passage time at all, let alone described how it works. In the post interviews all students were able to describe factors that affect the setting for passage time as well as the effects passage time has on the overall phase. Additionally, students knew how the timer works. This concept was explicitly depicted in five activities with MOST animations. Students observed, discussed, collected data, and performed basic calculations while watching simulations to determine the relationship between passage time and detection zone length and maximum allowable headway to identify the role passage time plays in intersection efficiency and establish the effect of a minor street's passage time setting on the major street. In the reflective survey, students expressed that the activities in lab helped enforce theories discussed in class. Student 41 acknowledged the difficulty of this particular concept and believed that all forms of presentation were supplementary to their understanding.

> ***Student 41:*** *Passage time was one of the more difficult timing parameters to understand and furthermore estimate. So I believe a combination of all material used to cover this topic was effective. Different ways the concept was presented gave a different view into how the timing parameter affected a signalized intersection.*

Twenty of the twenty-eight students from cases B, C, and D were also able to correctly show how the passage time works in question twenty-three of the post interview. Twenty students were also able to describe the relationship between passage time and detection zone length in question seven. Eighteen students suggested adjusting the passage time when phases are either terminating too early or extending too long in question fifteen. A higher proportion of students from Case A were able to articulate different relationships and effects that deal with passage time, but most students from the other three cases had comparable understandings of these concepts. In conclusion, the activities with MOST animations were effective for student learning, but students exposed to MOST did not learn substantially more than students in cases B, C, and D.

Concept 4: Minimum Green Time

Students exposed to MOST animations understood the purpose of minimum green time more than students who were not exposed to MOST animations as seen in Figure 8.

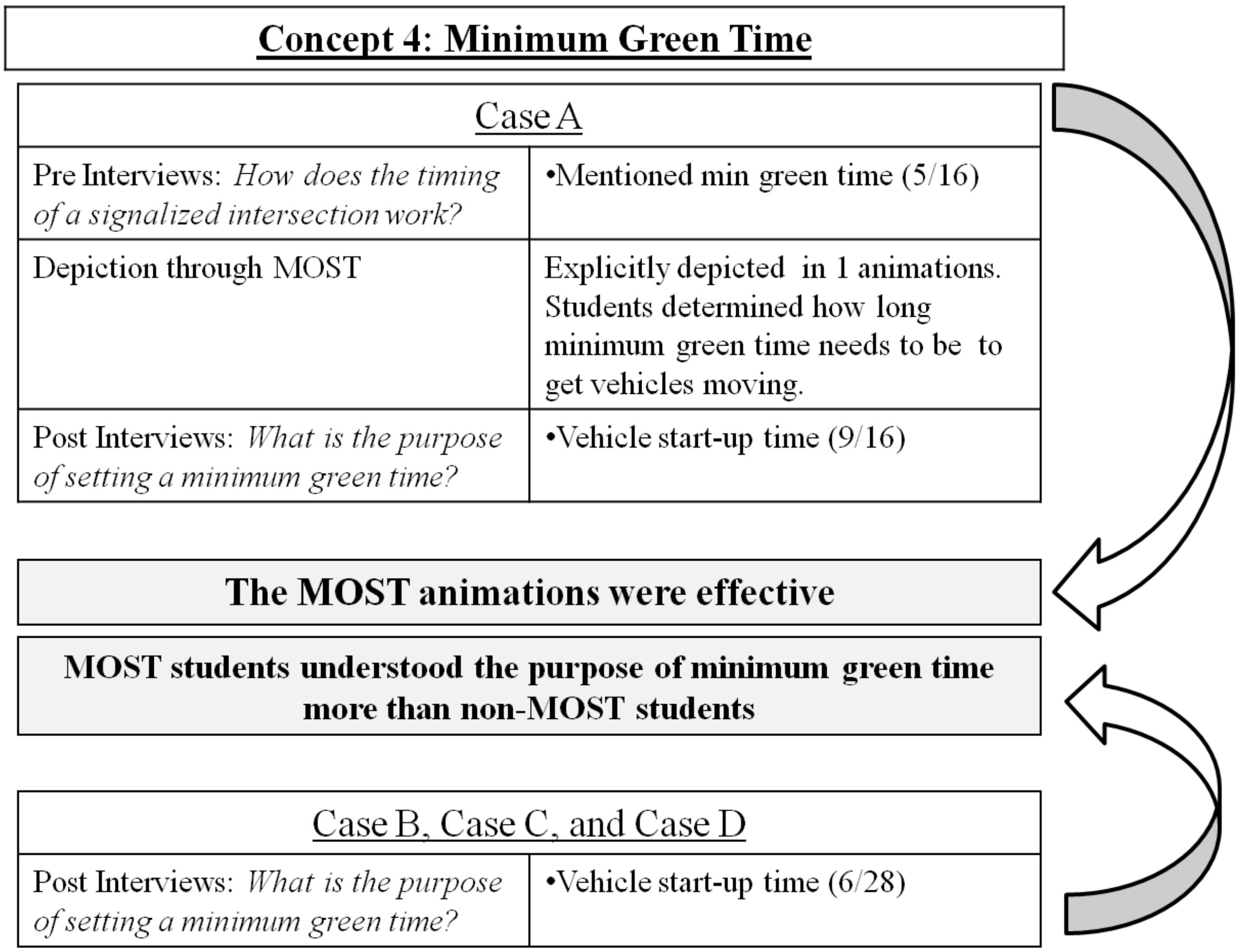

Figure 8. Results for Concept 4

Pre Interviews

As previously mentioned, to uncover existing knowledge students had prior to the traffic systems course they were asked to describe how the timing of a signalized intersection works in question two of the pre interview. In describing actuated control, only five students mentioned minimum green time. In their descriptions, these five students either noted that it was a timing parameter or explained that a phase would have to remain green at least that amount of time. Not one student described its purpose or why it was important.

Post Interviews

In the post interviews students were directly asked what purpose the minimum green time serves in question eighteen. Nine students indicated that minimum green time is to allow for vehicle start up time at the beginning of a phase, three students said it is intended to satisfy drivers' expectations, and three students believed it was to ensure complete clearance of the initial queue. Most students explained how drivers need to react once a light turns from red to green. Those students who indicated that minimum green time is set to satisfy drivers' expectations gave the example of one car in queue and explained that the one vehicle should be able to clear the intersection before the phase changes. These two responses are reasonable descriptions for the purpose of minimum green time. However, the students who indicated that minimum green time ensures clearance of the initial queue did not quite understand its true purpose.

> ***Student 42****: For a busy intersection, let's say there's cars always coming constantly, constantly, you can't help with that, right? So your minimum green time is a minimum amount of green time you're going to give cars to go, and no matter what, no matter if there's a call placed on another phase, then that amount of green time will always be used for that particular phase.*

Student 42 believes that minimum green time is to ensure that a certain number of vehicles make it through an intersection regardless of calls on conflicting approaches. Most students responded in one of the prior two ways and did appear to understand the purpose minimum green time.

In post interview question twenty-three students were asked to graphically show the value of each timing parameter for the duration of the green indication given the detector status. All sixteen students were able to show the correct timing pattern for minimum green. They all showed the minimum green timing down from the beginning until it reached zero. Students understood how this timing parameter works.

Interpretations

The MOST animations appear to be effective in helping students understand the purpose of minimum green time. At the beginning of the semester students could not provide much insight regarding the minimum green time. By the end of the term they all knew how it worked and most of them could accurately articulate its purpose. The concept of minimum green time was the main idea in one of the activities with MOST animations. In this activity students collected data and performed basic calculations while watching the simulations to determine the role that minimum green time plays in producing efficient intersection operations. This was done by observing simulations with varying values of minimum green time and deciding when it is too large. This concept was also presented in lecture and practiced in homework assignments. In the surveys, about half of the students indicated that the activity helped them understand the purpose of minimum green time. The rest of the students felt that a combination of lecture and readings was adequate for learning the concept. The conceptual change that was observed can therefore be linked in part to the MOST animations.

All of the students from the other three universities were also able to show how the minimum green time works on question twenty-three of the post interview. However, not as many could describe its purpose in question eighteen. Fourteen students from Case B, Case C and Case D thought that the purpose of minimum green time was to satisfy drivers' expectations. This justification is valid, but there is no science behind the term alone with no example or explanation. Six students mentioned vehicle start up time in addition or instead of drivers' expectations, which is the most correct response. Six students thought that the main purpose of setting a minimum green time was to ensure that a certain number of vehicles could make it through in each phase. There was an additional response common among these three cases that did not come up once in Case A. Eight students were under the impression that minimum green time should also account for pedestrian crossing time. Many actuated intersections do have additional timing parameters in place to account for pedestrians, but pedestrian crossing time has nothing to do with the role of the minimum green time.

Students do not have difficulty understanding how minimum green time works, but there is some confusion regarding its role. A much higher proportion of students from Case A indicated that the minimum green time allows time for vehicles to get moving at the beginning of green. This response has the most science behind it. The misconception that pedestrian crossing time should be a consideration when setting the minimum green time was prevalent in Case B, Case C, and Case D but did not come up at all in Case A. In conclusion, the students exposed to MOST animations knew the purpose of the minimum green time better than students who were not exposed to MOST animations.

Concept 5: Maximum Green Time

Students exposed to MOST animations understood how maximum green time works better than students who were not exposed to MOST animations as seen in Figure 9.

Concept 5: Maximum Green Time

Case A	
Pre Interviews: *How does the timing of a signalized intersection work?*	•Mentioned max green time (5/16)
Depiction through MOST	Implicit in 5 activities through observations of phase termination and delay
Post Interviews: *Show value of timing parameters on chart for given detector status.*	•Correct (14/16)

The MOST animations were effective

MOST students understood how maximum green time works more than non-MOST students.

Case B, Case C, and Case D	
Post Interviews: *Show value of timing parameters on chart for given detector status.*	•Correct (10/28)

Figure 9. Results for Concept 5

Pre Interviews

Students' preconceptions about maximum green time were obtained by asking them how the timing of a signalized intersection works in question two in the pre interviews. Only five students brought up maximum green time in their description. As was discussed previously, most students defined actuated control as an intersection that responds to vehicles through detection.

Post Interviews

During the post interviews students were asked to list possible solutions for phases that terminate too early or extend too long in question fifteen. Six students suggested adjusting the maximum green time for phases that terminate too early and four suggested adjusting the maximum green time for phases that extend too long. They also provided more details on when and how to adjust the max green time as seen in Student 32's response.

> ***Student 32:*** *Terminating too early, that means there's still cars in the queue. So I would say you could probably extend the max green time a little bit, if possible, because by extending that, you'd hopefully be able to get in those last few cars that didn't make it through. And then if it's too long…you might want to reduce the max green. Or the passage time too, yeah. Reduce max green or reduce passage time.*

Student 32 accurately describes how to adjust the maximum green time to increase efficiency of intersection operations. Those who brought up maximum green time gave accurate descriptions, but not all students mentioned it in their response to this question.

In question twenty-three students were asked to graphically show the value of each timing parameter for the duration of the green indication given the detector status. Fourteen students appropriately showed the maximum green timer counting down starting once a call was received on the conflicting phase. Two students incorrectly started the maximum green time from the beginning of the green indication.

Interpretation

The MOST animations were effective in helping students learn about maximum green time. Students from Case A developed a strong understanding of how the maximum green time works. Many students were also able to describe the effects of maximum green time on intersection operations, which were observed in their suggested solutions for phases that terminate at suboptimum times. Relationships involving maximum green time were presented to students in one of the activities with MOST animations. In this activity students watched simulations with varying values of maximum green time to understand the effects of this timing parameter on the efficiency of the intersection. In the survey students expressed that the activity in lab was helpful in learning about maximum green time. There were a few students who claimed that the lecture alone was adequate for understanding maximum green time.

Ten students from Case B, Case C, and Case D also provided recommendations that involved the maximum green time for phases that terminate too early or extend too long in their response to post interview question fifteen. This proportion is comparable to the number of students from Case A who could articulate these effects. However, in question twenty-three where students were asked to graphically show the value of each timing parameter given the detector status there was a prevalent misconception. A total of eighteen out of twenty-eight students from Case B, Case C, and Case D illustrated that the maximum green time begins counting down at the start of the green indication. This is incorrect; the maximum green timer does not start timing down until a call has been placed on a conflicting phase as indicated by fourteen out of the sixteen students in Case A who were exposed to the MOST animations. Students who were exposed to MOST animations learned how maximum green time works better than students who were not exposed to MOST animations.

Misconceptions

There were several misconceptions identified in this study. A misconception could be recognized when multiple students from more than one of the cases answered questions about a certain concept either incorrectly, inconsistently, or correctly but with inaccurate logic in their explanation.

For example, the incomplete notions students from Case A expressed about phases that extend too long in post interview question fourteen was prevalent amongst cases B, C, and D as well. Nearly all students suggested unused green time was an indication of a phase that is extending too long. This is true, however before this would occur another critical occurrence would be observed; the initial queue would dissipate. This could be indicated by unused green time, but it could also be seen if vehicles are able to drive through an intersection without stopping while vehicles are in queue on a conflicting approach. This will increase the average delay for vehicles in queue at the conflicting phases which is a measure used in determining overall efficiency of intersection operations. This was noted as an area of conceptual change in Case A because more students were able to articulate a complete set of characteristics in their response during the post interviews, but this was not the case for all students.

Post interview questions eight and twelve involved observing and discussing two of the MOST animations. The animation in question eight was intended to show the effects of different detection zone lengths on the overall phase termination for two identical intersections. Twelve of the sixteen students from Case A, and about half of the students from the other three cases were able to correctly identify that the phases ended in gap outs and they terminated at different times due to the difference in detection zone lengths. The rest of the students seemed to identify observable patterns that they associated with max outs or gap outs to determine the reason for termination. An example of this is as follows.

Interviewer: *Did these phases terminate in a gap out or max out?*

Student 21: *This one has a max out, I think. But I couldn't focus on this one.*

Interviewer: *And why do you say that one is a max out?*

Student 21: *Because my queue was not served completely.*

In this case, Student 21 knows that for an appropriately timed intersection a gap out occurs when the entire queue has been dissipated. If a phase terminates and not all of the cars have been served then the phase likely terminated due to a max out. If asked to explain the process in which a phase would gap out or max out students could accurately do so, but immediately after would misidentify one or the other when watching an animation.

There was also some confusion regarding the purpose each timing parameter serves. Eight students from cases B, C, and D brought up pedestrian crossing time when asked about the purpose of setting a minimum green time. In reality pedestrians are not considered when determining the minimum green time for an intersection, they are accounted for through different means. Students who also mentioned that minimum green time helps satisfy driver expectations were correct. Not as many students brought up the fact that the first couple vehicles in queue need time to start up before saturation flowrate can be reached and the passage time can take over. This description has the most scientific support and was most prevalent in Case A. There were still students across all cases that were unable to identify the role of minimum green time in actuated control. The following response shows a student's partly correct way of thinking about the purpose of minimum green time.

Student 13: *The minimum green time is somewhat based on pedestrian movements. It allows them to safely cross the road so you don't have green-- oh, there's no car, switch back to yellow and catch them in the middle of an intersection. And, also, to, I guess, service a couple cars. You don't want it too short.*

Student 13 mistakenly brings up pedestrian movements then goes on to suggest that the minimum green time ensures that light will stay green for at least the first couple vehicles. This student was not able to articulate how the minimum green time accomplishes this.

A similar misconception was found with the maximum green time. In question twenty-three of the post interview students were asked to show the value of each timing parameter in the form of a chart for a given detector status. Eighteen out of twenty-eight students misidentified the time and mechanism leading to phase termination. The most common error made by students was starting the maximum green timer at the beginning of the phase rather than at the presence of a call on a conflicting phase. Only two students from Case A had this misconception.

CONCLUSION

The MOST animations improved students' understandings of the proper duration of the green indication. This concept was implicit in five activities involving MOST animations. Interactions with the MOST animations and peers created experiences for students to refer to when responding to questions regarding this concept such as question fourteen from the post interview where students described what it meant for a phase to extend too long. Eight students from Case A gave refined responses based on their recent experience with the MOST animations. Students who limited their response to unused green time were likely referring to preconceptions they had from past experience as drivers because they gave contextual examples from being frustrated at a red light while no vehicles are on the active approach. Students' understandings of the relationship between cycle length and delay also improved, but this could not be directly linked to the MOST animations. Students across all cases understood this concept. Results from reflective surveys suggest that current graphical displays used to represent this concept are adequate for student learning.

Conceptual change was more obvious in students' understandings of the timing parameters; passage time, minimum green time, and maximum green time. Three of the MOST animations explicitly depicted concepts related to passage time. Through this, students learned the role of passage time in the timing systems by observing headways in a departing queue, relating headways to passage time, and determining how the passage time on a minor street affects overall intersection operations. These relationships were made more obvious through the animations than current static displays, which is one reason why animations often facilitate learning. Students from all cases understood how minimum green time works, but not as many understood its role in the timing system. A higher proportion of students from Case A correctly noted vehicle start up time when describing the role of minimum green time than cases B, C, and D. Again, when describing the purpose of minimum green time, vehicle start-up time has more scientific support than the justification of driver expectations alone. One of the MOST animations directly addressed this concept. In the activity students discussed the role of minimum green time while watching the simulations which created an experience for the students to refer back to during future constructive thought. The MOST animations also improved understanding of maximum green time. The purpose of maximum green time was understood across all cases, but only students in Case A understood how it works. This concept was depicted in one MOST animation. The controller status displayed in each animation showed students when each timer starts while the simulations are running; a cue that students were able to pick up on. Students from cases B, C, and D did not pick up on this dynamic relationship because they were limited to static representations where relationships over time were merely implicit. Students from Case A who did not understand each concept probably had difficulties applying their newly acquired perceptions to new contexts which can be difficult to overcome with animations. However, the structured activities that guide students through the animations helped in overcoming this drawback for most students.

Researchers at UI addressed the need for additional representations to demonstrate concepts related to traffic signal operations with the MOST approach to learning. Results from this pre-post-comparative case study suggest that these researchers were successful in their endeavor and animations were helpful in students' understandings of dynamic processes related to actuated control. They will graduate with accurate understandings of these concepts and will be prepared for engineering practice if they pursue a career in transportation engineering.

Further development and evaluation of similar learning tools could greatly benefit the way certain concepts are presented to students in the classroom.

Results from this study could also have broader implications than signal timing. Many areas of civil engineering such as wastewater treatment and structural analysis also deal with dynamic processes or reactions that could be easier to understand if observed in an animation representation. For example, when dealing with the dynamic response of a structure, a modal analysis provides frequencies in the form of a vector. A dynamic simulation showing the different mode shapes might improve students' understandings of the dynamic response. This could be an area of future research in engineering education.

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