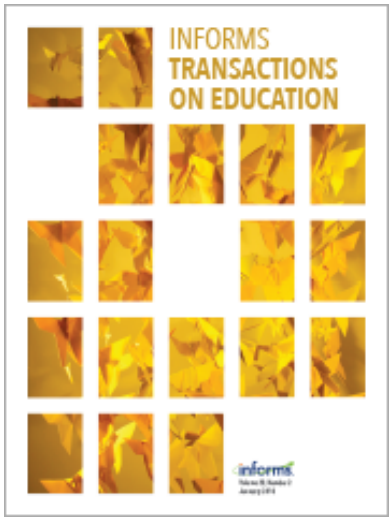

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Thomas C. Sharkey, Sarah G. Nurre

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Video Tutorials Within an Undergraduate Operations Research Course: Student Perception on Their Integration and Creating A Blended Learning Environment

Thomas C. Sharkey
Department of Industrial and Systems Engineering, Rensselaer Polytechnic Institute, Troy, New York 12180, sharkt@rpi.edu

Sarah G. Nurre
Department of Industrial Engineering, University of Arkansas, Fayetteville, Arkansas 72701, snurre@uark.edu

In this paper, we discuss the impact of video tutorials on an undergraduate operations research (OR) course and analyze important aspects of student perception of their impact on the learning experience. Supplementary video tutorials offer additional examples of OR concepts; thus, class time can be more focused on letting students gain intuition about these concepts. We analyze students' survey responses to help determine the perceived impact of the video tutorials on office hours and whether students' familiarity with the creator of the tutorials impacted the tutorials' effectiveness. Our results demonstrate that students saw significant advantages in using these supplementary video tutorials and that the creator of the tutorials did not impact the tutorials' effectiveness as long as they were properly integrated into the course. Therefore, our results show that the overhead required to offer online video tutorials may be low (i.e., similar to selecting a course textbook) since their success relies more on proper integration into the course than having the professor of the course produce them. In addition, a preliminary assessment demonstrates that our blended learning environment has a positive impact on the learning experience.

Keywords: online video tutorials; student perception; blended learning
History: Received: May 2015; accepted: December 2015.

1. Introduction

In this paper, we focus on our experience with introduction and use of video tutorials to support an undergraduate operations research (OR) course. In particular, the video tutorials supported course delivery of ISYE 4600: OR Methods at Rensselaer Polytechnic Institute (RPI), a required course for all Industrial and Management Engineering undergraduates. The video tutorials were designed to present "virtual office hours" in that they provided new examples and applications of models and methods discussed during class. Therefore, these tutorials supplemented the traditional classroom experience, rather than replacing it, to create a blended learning environment. This environment places an emphasis during class on students gaining intuition about an OR concept (which could include a new modeling approach, problem, or method) and then working through an example of the concept. The video tutorials provide an additional example of the concept. We continue to emphasize the value of the classroom experience but we leverage the online content delivery to enhance the overall learning experience.

For a particular OR concept, students are initially challenged to solve a particular problem before the formal presentation of the concept. Students are given between 10 and 15 minutes to tackle the problem and discuss their approaches with each other. This allows the students not only to solve the problem but also to think about their approach in detail because they have to present it to others. Therefore, the students are engaging in an active learning activity before the formal presentation of the concept. Overall, the classroom experience involves (i) an opportunity for students to gain intuition about an OR concept, (ii) the formal mathematical presentation of the concept, and (iii) an application of the concept to an example that the students already understand. The video tutorials supplement this experience by providing students with additional examples to practice the OR concept and a real-time discussion of how to solve the additional example. Essentially, the availability of the video tutorials makes it less necessary to work through multiple examples of the same concept in class. The time saved is leveraged to provide an active learning opportunity.

Active learning has been shown to be effective in OR classrooms (Liebman 1994, 1998; Richards et al. 1995; Cochran 2005, 2012, 2015; DePuy and Taylor 2007; Kydd 2012). The learning experience we create is similar to a blended learning environment. In class, students participate in active learning activities and traditional lectures; outside of class, students can choose to view the video tutorials to see supplementary examples. An instructor who wishes to provide video tutorials for each OR concept faces a challenge because of the time required to create and integrate them into their class. Thus, one contribution of this paper is to analyze the perceived effectiveness of video tutorials created and published by someone who is unknown to the students (i.e., a person with whom the student does not interact outside of viewing their video tutorial). We surveyed students and found that a proper integration of the video tutorials into the course is perceived as much more important than the identity of the tutorial's creator. We believe that this is a significant contribution because it indicates that a professor can select and curate available online supplementary video tutorials to enhance the students' learning experience without the full overhead of creating this content.

Our classroom experience with active learning and the use of the supplementary video tutorials is related to flipped classrooms but does not require students to watch video lectures outside of the classroom; instead, we use the video tutorials strictly as supplemental online content. There are two reasons that this type of blended learning environment was implemented in a flipped classroom environment. First, there are typically between 50–60 students enrolled in ISYE 4600 with one instructor and one teaching assistant. Therefore, even if the students worked in groups of five in the flipped classroom environment, we were worried about how to assist students in a timely manner. Second, ISYE 4600 is one of the flagship courses in our curriculum and is a pre-requisite for many of our technical electives. Therefore, we were hesitant to change its delivery too much without having implemented a flipped classroom environment in a more advanced, smaller enrollment course. Our blended approach overcame these two challenges because it is not necessary for the professor to "circulate" during our active learning opportunities and because it continues to incorporate a traditional lecture component.

A potential disadvantage of our environment is that it continues to use traditional lectures and, therefore, will not offer the same level of active engagement as a flipped classroom. Our focus on active learning opportunities to build OR concepts could be implemented in a flipped classroom where each class ended with the students focusing on the intuition-building activity for the next concept, working through the required content on the concept outside of class, and working through examples of the concept during the next class. However, instructors would need to properly manage time to ensure that enough was left towards the end of class to work through the intuition-building activity.

The fact that our video tutorials were supplementary and not required differentiates them from some of the previous work that integrates online content into an OR classroom. For example, Troxell (2002) and Hardin and Ellington (2005) leverage video tutorials to aid in implementation of models in a modeling language in OR courses in order to expand the topics covered in class. These video tutorials were *required* viewing as part of the learning experience.

Seal and Przasnyski (2003) use video tutorials, along with a variety of other interactive, online methods, for teaching OR in an MBA course. Leon et al. (2007) focus on interactive tutorials, asking students to complete tasks during the viewing of the video tutorial. They then evaluated the effectiveness of such a voluntary interactive learning experience on students' ability to solve a transportation problem (Seal et al. 2010). Note that our video tutorials were not story-boarded as were those of Seal and Przasnyski (2003); we believe this helps the tutorials to feel more like interactions between a professor and a student during traditional office hours (thus we call them "virtual office hours"). This aspect of our video tutorials also makes them less time-consuming to create and publish which could increase the likelihood of others adopting a similar model for creating their own video tutorials. Nurre and Sharkey (2013) examine the impact of a set of voluntary video tutorials on an undergraduate OR course. Our work is similar to this line of previous research in the sense that the video tutorials are voluntary. We differentiate our research on the *impact* of the video tutorials and their integration into the course by addressing four key components: (1) how the voluntary video tutorials can help to create a blended, active learning environment; (2) the impact of these video tutorials on the office hours of the professor and teaching assistant; (3) the perceived impact of video tutorials created by someone outside the class and with whom students have had no interaction beyond the use of the video tutorials; and (4) a preliminary examination of the impact of our blended learning environment on student performance. The third aspect of our analysis is particularly important as it provides insight into the ability of others to integrate selected (and verified accurate) but not homegrown videos into their courses.

Use of video tutorials is related to the growing trend of massive open online courses (MOOCs). Daniel (2012) and Herman (2012) provide overviews of these types of courses and Terwiesch and Ulrich (2014) discuss their potential impact on MBA programs. Use of our video tutorials provides benefits associated

with many MOOCs, such as their convenience and "on-demand" nature, without discarding the benefits of a traditional classroom setting, and thus creating our blended learning environment. Note that our blended learning environment provides an *optional* online component and is thus distinct from "required" blended environments (see, for example, Tuckman 2002, Mayadas et al. 2009, DeVaney 2009, and Scherrer 2011). In our blended learning environment we use class time for students to gain intuition about an OR concept by actively trying to solve a sample problem, seeing the formal presentation of the OR concept on the sample, and providing the optional online supplement of an additional example presented through the video tutorial.

Creation of these video tutorials began with the second author's desire for more teaching experience; however, doctoral students are not allowed to teach a course at RPI. Therefore, she created an initial set of video tutorials (nine of which are still in use) in Fall 2012. The first author created four additional video tutorials in Fall 2013, nine in Fall 2014, and three in Fall 2015. Students in the Fall 2013 and 2014 classes (which were included in our survey analysis) had no interaction with the second author who created the initial set of tutorials but could view all tutorials. Therefore, we are able to understand how student use and perception of the video tutorials is impacted when the students do not know the person who created the videos. This paper is similar to Nurre and Sharkey (2013) as it addresses student use and perception of video tutorials; however, it builds on this previous work by examining how to more effectively blend these tutorials into a course and the potential impact of using tutorials created by someone other than the course professor.

This paper is organized as follows: In Section 2, we discuss how we integrate the video tutorials into the ISYE 4600 curriculum and how the videos altered course delivery to create a blended learning environment. In Section 3, we analyze online survey responses on student use and the perceived impact on student learning experience. An important conclusion from this analysis is that video tutorials created by someone outside the class (and unknown to the students) can be as effective as videos created by the professor. In Section 4, we provide a preliminary assessment of the positive impact of our blended learning environment on student performance. In Section 5, we discuss lessons learned about these video tutorials and ways in which others could integrate them or similar content into their classrooms.

2. The OR Course Curriculum and the Integration of Video Tutorials

ISYE 4600 provides a comprehensive overview of deterministic and stochastic OR concepts; therefore, it is typically fast-paced. In Table 1, we provide an outline of the course by topics, the approximate number of weeks spent on each major topic, and the titles of their associated video tutorials along with the semester in which they were produced. In the appendix, we provide a description of each video tutorial. The video tutorials, along with background material, is available at http://homepages.rpi.edu/~sharkt/ORMVideos.html.

This course schedule is dense; the video tutorials allowed us to lighten the amount of material covered in class (e.g., show fewer examples of a method). Rather than focusing on presenting multiple examples of a concept, class was structured to give students an opportunity to gain intuition about the concept before its formal presentation. The activities to support this process involved presenting students with a "challenge problem." Students are asked to solve the challenge and discuss their solution/approach with others. Typically, we provide 10–15 minutes of class time to focus on this process (around the length of a video tutorial covering an additional example). Here is the type of "challenge" used before discussing linear programming (LP) models, which is similar in spirit to the example of Pendegraft (1997) and extended by Cochran (2015):

Example 2.1 (A Lego Workshop Example). My children have been making small Lego items and sending them to family members. In particular, they make a "Tee (pictured left in Figure 1)" and a "Cake (pictured right in Figure 1)." They are interested in launching a Lego Workshop to make money: You need to help them figure out how many of each item to make per week. They estimate that they can sell tees for \$3 per tee and cakes for \$2 per cake. Each tee requires 2 small bricks and 1 big brick, while each cake requires 1 small brick and 1 big brick. They can procure 100 small bricks and 80 big bricks for their workshop per week (free of charge from their parents). They have been told that they will be unable to sell more than 40 tees in a week but there is an unlimited demand for cakes. How many tees and cakes should they make per week? Think about how you arrived at your solution. Is there a way to formalize your solution procedure?

In response to this challenge, many students make accurate observations about properties of the optimal solution including that we need to use all available units of at least one of the resources. This sets the foundation for students understanding the key idea behind the simplex method and the optimality of an extreme point for LPs. Note also that some students state that the revenue per brick is equal to \$1 for the tee and cake and, therefore, you cannot make more than \$180 (which is the optimal solution when you make 20 tees and 60 cakes). The class resumes by focusing on formulating this example as an LP and applying the

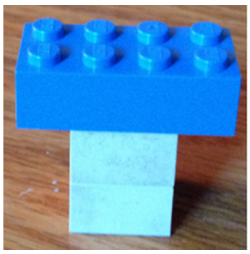
Table 1 ISYE 4600 Course Schedule and Associated Video Tutorials (as of Fall 2015)

Course topics
Linear programming (4 weeks)
Modeling and applications
Tutorial 1: (Fall 2012) Modeling and solving a cat's daily menu as an LP
Tutorial 2: (Fall 2014) Modeling a bigger Lego workshop example as a linear program
The simplex method
Tutorial 3: (Fall 2012) Solving a maximization LP with the simplex method
Tutorial 4: (Fall 2012) Applying the two-phase method to a linear program
LP software
Tutorial 5: (Fall 2012) Modeling and solving a supermarket sweep problem as a linear program
Tutorial 6: (Fall 2014) Solving the bigger Lego workshop example using excel solver
Duality and sensitivity analysis
Tutorial 7: (Fall 2014) A takeover of the Lego workshop and its role as the dual linear program
Tutorial 8: (Fall 2015) How much to pay for more bricks in the Lego workshop? The role of shadow prices
Network optimization (2 weeks)
Shortest path problem
Tutorial 9: (Fall 2012) Applying Dijkstra's algorithm to solve a shortest path problem
Maximum flow problem
Tutorial 10: (Fall 2014) Applying the augmenting path algorithm to solve a maximum flow problem
Transportation problem
Tutorial 11: (Fall 2013) Modeling a golf team assignment as a transportation problem
Minimum spanning tree problem
Tutorial 12: (Fall 2015) Applying Prim's algorithm to solve a minimum spanning tree problem
Integer programming (2 weeks)
Modeling and applications
Tutorial 13: (Fall 2012) Modeling and solving a farmers market problem as an integer program
Tutorial 14: (Fall 2014) Modeling an auction-based fantasy football draft as a binary integer program
Branch and bound method
Tutorial 15: (Fall 2012) Applying a branch and bound algorithm to solve a minimization integer program
Multi-objective optimization (1 week)
Goal programming
Tutorial 16: (Fall 2014) Modeling a monthly budget problem as a goal program
Efficient frontier
Tutorial 17: (Fall 2012) Determining the efficient frontier of a call center staffing problem
Decision analysis (1.5 weeks)
Decision rules
Decision trees
Tutorial 18: (Fall 2013) Double Dare and decision trees
Tutorial 19: (Fall 2014) Deciding the top pick in a draft with decision trees and expert predictions
Markov chains (2 weeks)
Steady-state equations
Tutorial 20: (Fall 2013) Modeling chutes and ladders as a Markov chain and its steady-state probabilities
Advanced properties
Tutorial 21: (Fall 2013) First passage times and the chutes and ladders Markov chain
Tutorial 22: (Fall 2014) Modeling a golf hole as a Markov chain and using absorption probabilities to analyze scores
Markov decision processes
Tutorial 23: (Fall 2015) Modeling a market share and advertising problem as a Markov decision process
Queueing theory (2 weeks)
Little's law
Tutorial 24: (Fall 2014) Applying Little's Law to a new stadium screening procedure
Birth and death processes and M/M/s models
Tutorial 25: (Fall 2012) The I Love Lucy chocolate factory as a queueing system

graphical method. The students can use a video tutorial on a linear programming model with two variables to supplement these concepts. Therefore, all students have an opportunity to gain intuition about the concept and to see an in-class example applying the concept to a problem with which they are already familiar. After class, should the student deem it necessary, they can supplement the class material with the video tutorial.

Similar challenges are integrated into ISYE 4600 throughout the semester. These include: (1) asking students whether they would accept "Shark Tank" type deals for the Lego Workshop to introduce the concept of sensitivity analysis and shadow prices, (2) asking students to find the quickest way to move between favorite rides at Disney World to introduce the shortest path problem, (3) determining the number of times we

Figure 1 Lego Items Sold in the Lego Workshop



(a) Lego tee

(b) Lego cake

can move between favorite rides at Disney World to introduce the maximum flow problem, and (4) playing through a round of Deal or No Deal (see, for example, Chan 2013) to introduce decision analysis and utility theory. In addition to allowing class time dedicated to these challenges, Nurre and Sharkey (2013) explain how the video tutorials can enhance the content of ISYE 4600 in the following ways:

- *Presentation of a Larger Number of Classic Applications*: During the linear programming section of ISYE 4600, the lecture included examples on resource allocation, personnel scheduling, and mixing problems. A video tutorial captured another classic linear programming example, i.e.,creating a diet plan.
- *Alternative Presentation of an OR Method*: In the network optimization section of ISYE 4600, a visual description of Dijkstra's shortest path algorithm was presented where the network was split into red nodes (whose shortest path have been found) and blue nodes (whose shortest path have not yet been found). The associated video tutorial with the shortest path problem focused on presenting the method in a more algorithmic manner.
- *Detailed Presentation of Different Cases of a Problem*: During the integer programming section of ISYE 4600, the lecture included going through branch and bound for a maximization integer program. The associated video tutorial on branch and bound provided a minimization example.

3. Student Use and Perception of the Integration and Impact of Video Tutorials

To understand the impact of the video tutorials on the learning experience, we distributed an online survey to all students who took ISYE 4600 in Fall 2013, Fall 2014, and Spring 2015. This group had no interaction with the doctoral student who created nine of the video tutorials currently in use and represents a different set of students than those surveyed in Nurre and Sharkey (2013). The online survey, created using Google Forms, was distributed to 121 students. There were 51 respondents (19 from Fall 2013, 31 from Fall 2014, and 1 from Spring 2015), for an overall response rate of 42.1%. Our assessment of the video tutorials focuses on analysis measuring the "student perception" dimension of an effective learning experience (see Kane 2012). In Section 3.1, we provide an overview of student use and the perceived impact of the video tutorials on their learning experience. In Section 3.2, we discuss the impact of the video tutorials on office hours during the semester. In Section 3.3, we discuss the perception of the video tutorials created by someone unknown to the students.

3.1. Student Use and Perceived Impact on the Course

In this section, we focus on analysis of students' video tutorials use and their perceived importance in reinforcing concepts from lecture, completing home work, and preparing for the exam. Note that Nurre and Sharkey (2013) examined, for a different set of students, the number of video tutorials watched by a student and the perceived importance of the tutorials in reinforcing class material. They did not examine the impact on home work and exams. Overall, of the 51 respondents, 25% indicated that they watched all of the video tutorials, 47% watched "most," 18% watched "some," and 10% watched "a few."

In Table 2, we show the level of agreement of the students to three statements associated with the perceived importance of the video tutorials in helping students complete the course. The students agreed most strongly with the statement about the video tutorials helping to complete homework problems. At least 88% of students agreed (either responded "Strongly Agree" or "Agree") that the video tutorials helped enhance their knowledge of the material, approach homework problems, and prepare for exams.

3.2. The Impact on Office Hours

In Section 2 we discussed the impact of the video tutorials on the classroom experience, helping us to create active learning opportunities while maintaining a variety of examples of OR concepts. We also wanted to understand the impact, if any, of the video tutorials on ISYE 4600 office hours. Therefore, in the survey, we asked the level of agreement of the students with two statements associated with that impact. We present the responses in Table 3.

Responses to these statements indicate that students used the video tutorials to answer their own questions about the course material, thus decreasing the amount of time needed for office hours. To better understand the response to these statements, the survey also included an open-ended question: "Do you have any additional comments about how the video tutorials potentially changed the way you approached office hours?" Twelve students responded to this question

Table 2 Distribution (Out of 51) of Responses Pertaining to Questions on the Perceived Impact of the Video Tutorials on the Learning Experience

Statement	Median	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
The video tutorials enhanced my knowledge of the material.	4.62	0 (0%)	0 (0%)	0 (0%)	22 (43%)	29 (57%)
The video tutorials helped me approach the homework problems.	4.79	0 (0%)	0 (0%)	3 (6%)	11 (22%)	37 (72%)
The video tutorials were useful when preparing for the midterm and final exams.	4.35	0 (0%)	0 (0%)	6 (12%)	23 (45%)	22 (43%)

along the lines that they would still come to office hours *after viewing the video tutorials*. They commented that their visit would be more productive because their simple questions were answered by the video tutorials and they could focus on getting a deeper understanding of the material. In addition, multiple students commented that they preferred the greater flexibility in terms of *when* they could have their questions answered as the video tutorials could be watched on their schedule.

3.3. Perceived Impact of an "Unknown" Video Creator

We were further interested in knowing how students perceived video tutorials created by someone with whom they had no contact beyond the video tutorials. By specifically focusing on students who took ISYE 4600 from Fall 2013 and beyond, we surveyed those who had access to video tutorials created by the professor and by a post doctoral student whom the students did not know beyond the tutorials. This facilitated a direct comparison between these two types of video tutorial creators. In addition, we asked students their opinion on whether they would use video tutorials made by someone outside their home university, and how they viewed the video tutorials as opposed to recorded lectures. In Table 4, we present the distribution of responses in terms of their agreements with four statements pertaining to the video tutorial creators. We also included two open-ended questions: (1) How would you compare the effectiveness of video tutorials created by someone you knew with the effectiveness of video tutorials created by someone you did not know? (2) Do you have any additional comments about the effectiveness of videos created by someone you did not know?

The responses to the survey indicate that there is agreement (with 84% and 78% responding with at least an "Agree" to the first and second statement in Table 4) that the creator of the video tutorials did not impact their effectiveness or usefulness. This could indicate that students would benefit from the inclusion of "approved" video tutorials or online supplements in an OR class. In addition, there was agreement (78% responding with at least an "Agree") that students would use video tutorials created by people outside their home university. With respect to the open-ended question, 29 students stated that there was no impact on the effectiveness, 6 students expressed a preference for video tutorials created by the instructor, and 5 expressed an interest in having the tutorials created by someone other than the instructor to get a different perspective. However, in both these areas students stated that they would prefer to have video tutorials "approved" or "curated" by the course professor to ensure seamless integration into the learning experience. Students also stated that, although they prefer multiple approaches to the same problem (from using video tutorials), it was important that these approaches be graded in the same manner. In particular, there were nine responses to the open-ended questions, indicating that students appreciated an alternative viewpoint on an OR concept as this provided another opportunity for enhanced understanding of the materials. Students also expressed a preference for consistent terminology between the class and the video tutorials (e.g., nodes/arcs versus vertices/edges for network problems). One student stated: "*I believe these videos should be implemented in all classes as long as the information is seamless between the class and videos. If there are large gaps and unknowns, this will only create more confusion than no videos at all*."

Table 3 Distribution (Out of 51) of Responses Pertaining to Questions on the Impact of Video Tutorials on Office Hours

Statement	Median	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
The video tutorials decreased the amount of time I spent in office hours.	4.35	0 (0%)	0 (0%)	6(12%)	23 (45%)	22 (43%)
The video tutorials enabled me to answer questions on my own without the help of the teaching assistant and/or professor.	4.34	0 (0%)	1 (2%)	3 (6%)	22 (43%)	25 (49%)

Table 4 Distribution (Out of 51) of Responses Pertaining to Questions on the Impact of How the Video Tutorials Were Created on Their Effectiveness

Statement	Median	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
The video tutorials that were created by someone I did not know were effective in enhancing my knowledge of the material presented in the tutorial.	4.47	0 (0%)	1 (2%)	7(14%)	18 (35%)	25 (49%)
The usefulness of the video tutorials was not impacted by my previous interactions (or lack thereof) with the creator of the tutorial.	4.52	1 (2%)	1 (2%)	9 (18%)	14 (27%)	26 (51%)
I would use video tutorials created by those outside of my home university in the future should my professor make them available to me.	4.62	3 (6%)	3 (6%)	5 (10%)	11 (22%)	29 (56%)
The video tutorials were more effective than providing access to recorded lectures.	4.21	2 (4%)	3 (6%)	8 (16%)	17 (33%)	21 (41%)

Many students further stated that they would search for YouTube supplements for courses that do not offer video tutorials, but would often find it difficult to understand the creator/publisher. That students would search for additional online content is also demonstrated by the number of similar views received on certain video tutorials that we created. For example, as of November 3, 2015, the video tutorial on "Applying the Augmenting Path Algorithm to Solve a Maximum Flow Problem" has received 4,440 views on YouTube since it was posted in October 2014. In addition, a video tutorial on a goal-programming example has received 3,216 views on Vimeo. (Note that this video tutorial was not included in the current set of YouTube tutorials.) Clearly, students are using online content in their learning experience regardless of whether it is made available to them. A major concern is whether the material that students find accurately depicts the content and is of sufficient quality to enhance their learning experience. Students stated that online content that has been posted or "approved" by the professor or teaching assistant would be seen as much more effective. The six students who expressed a preference for professor-created video tutorials also expressed concern about the authenticity and/or correctness of the online content; they believe the course professor should vet the supplementary online material. This seems to indicate that integration of these video tutorials and/or other online supplements should be well thought out and that the course professor should follow a similar process as that used in selecting a course textbook.

We also asked students their opinions of the video tutorials compared to recorded lectures. Seventy-four percent agreed (i.e., answered either "Strongly Agree" or "Agree") that the video tutorials were more effective than simply making recorded lectures accessible. Based on responses to the open-ended questions, this can be explained by the fact that students viewed the tutorials as supplemental to lectures and that the role of the video tutorials is similar to that of an "interactive" course textbook. Thus, students did not simply learn through the traditional lectures but enhanced their understanding of the material through the video tutorials. Along these lines, students noted the benefits of the video tutorials over traditional textbooks because they could see someone actively working through an additional example and could compare their own attempt at the problem from the tutorial to the steps presented.

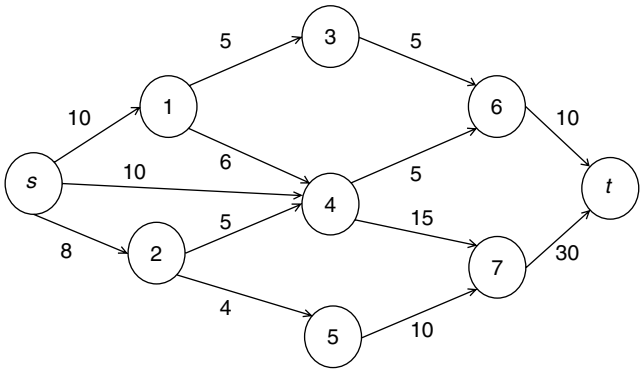
4. Preliminary Assessment of the Impact of the Blended Learning Environment

We provide a preliminary assessment of the blended learning environment by analyzing students' success on a midterm exam short answer problem that involves understanding duality to quickly identify the fact that we cannot improve the current network flow level. We examine student responses from Fall 2012 and Fall 2014, respectively, comparing those students who did and did not have full implementation of the blended learning environment. Our analysis is a limited approach to understand the true effectiveness of this environment. Although we are comparing different groups of students, our analysis does provide a preliminary assessment of the impact of the blended learning environment. The following is a sample short answer problem of which variations appeared on the midterm in Fall 2012 and Fall 2014.

Example 4.1. A water company operates the pipeline network that appears in Figure 2, in which each arc represents a pipe and is labeled with its capacity in thousands of gallons per day. You have been hired as a consultant to determine the maximum amount of water that can flow from source node s to sink node t in a day. The water company currently sends 28,000 gallons of water from s to t. Determine whether you can increase the flow from s to t, and provide a corresponding explanation for your reasoning.

A "high" level of achievement for this question would be to recognize that the $s-t$ cut of arcs $(s, 1)$, $(s, 4)$,

Figure 2 The Water Company's Pipeline Network



and $(s, 2)$ has a capacity of 28,000, thus implying that the water company cannot increase the flow because of the primal-dual relationship of the maximum flow and minimum cut problems. A "medium" level of achievement would be to correctly apply the augmenting path algorithm in this network to determine that the maximum flow is 28,000. A "low" level of achievement would be to incorrectly apply the augmenting path algorithm or simply to argue that you could increase the network flow.

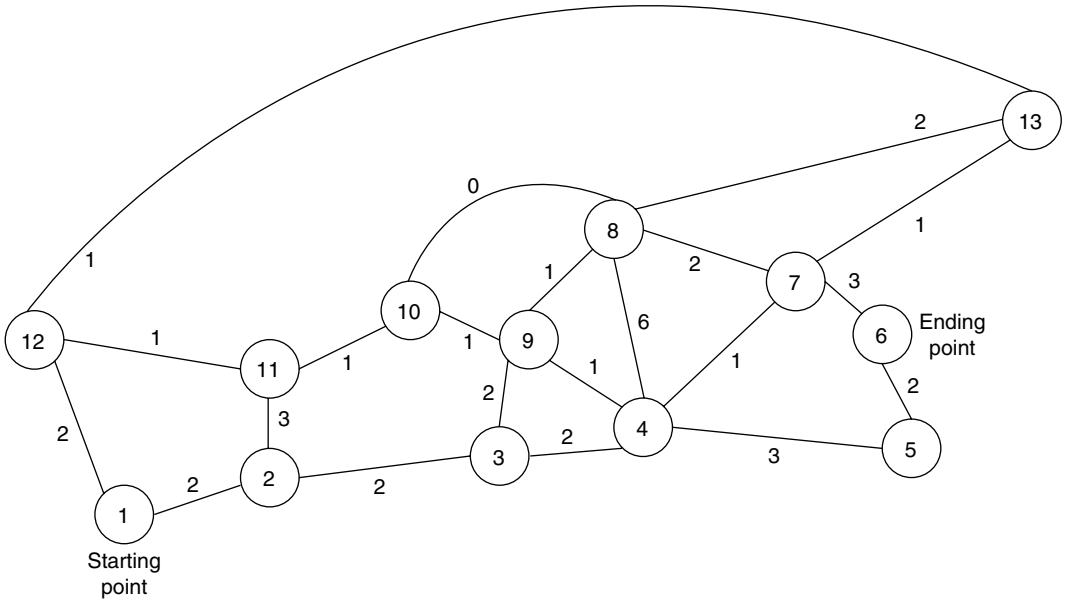
The active learning activity was built into the class in Fall 2013 (see Example 4.2); video tutorials discussing linear programming duality (Tutorial 7) and the augmenting path algorithm (Tutorial 10) were made available in Fall 2014.

Example 4.2. The network in Figure 3 represents the Magic Kingdom at Disney World. My daughter's favorite ride in the Magic Kingdom is at Node 1 of the network and my son's favorite ride is at Node 6. Each arc is labeled with the number of times my family is willing to walk that particular area of the park when we move from my daughter's favorite ride to my son's favorite (so you can ignore the "round trip" aspects of returning to my daughter's favorite ride). Can you: (i) determine the number of times my family will go from my daughter's favorite ride to my son's favorite? and (ii) provide an argument that nobody could increase your number?

The key intuition for Example 4.2 was to first determine that you can move between Nodes 1 and 6 four times and then to argue that you cannot increase on four since the total capacities of the arcs leaving Node 1 is four. Thus, the students would be leveraging the duality relationship between the maximum flow problem and the minimum cut problem in their argument. In class, most students could determine that the maximum network flow is four and, more important, seemed to immediately understand the minimum cut argument once it is made. The achievement levels on the midterm problem (Example 4.1) for Fall 2014 students were: 31/49 (63%) high, 10/49 (21%) medium, and 8/49 (16%) low.

For Fall 2012, the maximum flow section of the course did not include an active learning opportunity; the video tutorials on linear programming duality (Tutorial 7) and on the augmenting path algorithm (Tutorial 9) were not available to the students. The achievement levels on a problem similar to Example 4.1 were: 27/53 (51%) high, 14/53 (26%) medium, and 12/53 (23%) low. Thus, 12% more students achieved a high level of understanding on this problem in the blended learning environment and 7% fewer students achieved a low level of understanding. We emphasize

Figure 3 The Magic Kingdom Network with Arc Capacities



that this is only a preliminary assessment and that this change in achievement may not be solely attributable to the blended learning environment. For example, the maximum flow and minimum cut problems were discussed as part of the review for both classes and an example problem was discussed in preparation for the midterm. However, back exams were provided to students in Fall 2014; these exams could have placed an emphasis on understanding the different ploys for the short answer questions. A potential important area of future work, for another OR course (especially in an engineering curriculum) beginning to integrate a similar blended learning environment, would be assessment at a more rigorous level across all concepts, similar to the approach undertaken by Winch and Cahn (2015) for an introductory management science course (geared towards business students).

5. Lessons Learned and Discussion

In this section, we discuss some of the potential pros and cons of the video tutorials and present lessons learned on how to successfully integrate the tutorials into a course. We believe this discussion can serve as a starting point to those professors interested in integrating video tutorials and, in general, online content into their courses.

An Educational Opportunity for Doctoral Students: The initial set of video tutorials (created in Fall 2012 by a doctoral student going into the academic job market) were viewed as an educational opportunity for that student to gain teaching experience. In our opinion, creation of this type of online content gives the student teaching experience without the burden of organizing a full course. The doctoral student needed to be aware of and understand different learning styles in producing the content, especially given that the videos would be made publicly available. Therefore, the emphasis was on clearly and effectively presenting the concept in the video tutorial. In our opinion, this is of long-term importance in training doctoral students to become effective teachers, compared to being bogged down in course logistics. The doctoral student set up a website to receive feedback for her video tutorials and could receive a measure of the tutorial's effectiveness, which was used on her curriculum vitae as a demonstration of her teaching ability.

Video Tutorials, Online Content, and their Relation to Textbooks: In our opinion, the video tutorials (and other online content) can be used to supplement or replace a course textbook. One of the purposes of a textbook is to offer supplemental guidance to a student's learning experience by presenting the concepts in a complementary manner or applying them to different examples. Video tutorials accomplish this, and student surveys have emphasized their appeal over a traditional textbook because they present the thought process of the tutorial publisher as students work through the example. Several students stated that they would not have bought the course textbook had they previously known the OR course would have such a repository of online video tutorials. The key, though, is that the video tutorials and other online content be seamlessly integrated into the course so that a consistent (and complementary) message is presented about the concepts. Several students mentioned this aspect in their open-ended response to the effectiveness of the tutorials created by someone other than the professor (see Section 3.3). Therefore, if a professor wishes to leverage current video tutorials and online content, he or she must carefully search for appropriate online course content, similar to the care needed when selecting a textbook. Students stated that they find online content themselves; thus a professor who curates and integrates available content into their course can facilitate a more consistent (and professor-endorsed) message about the presented concepts. Note also that an important advantage online content instead of a textbook is that professors can "mix and match" content from different sources (free of charge) and create their own video tutorials if there is a gap in available online content.

Suggestions for Integrating Video Tutorials into Class: Based on similarities between the video tutorials and textbooks, we suggest similar approaches to selecting and leveraging supplemental tutorials. Begin by examining the available video tutorials (or other online content) to determine whether they properly support your course. For example, examine the descriptions of our video tutorials in the appendix to see if there is a subset that would be useful to the students in your course. Read the full problem description and view the video tutorial to make the final integration decision, similar to the way you would read through the relevant chapters of a potential textbook. If you choose to integrate a subset of the video tutorials into your class, we recommend treating and presenting them in a manner similar to "suggested course readings." In particular, note which video tutorials supplemented a particular lecture or homework problem. A student could then easily connect your presentation of the material to that of the associated video tutorial.

Suggestions for Creating Your Own Video Tutorials: To best capture our thought process as we addressed a particular problem, our video tutorials were not heavily scripted or storyboarded; we also did not choose to edit them. This meant a sharp decrease in the amount of time required to produce the videos. A downside of this approach is that certain video tutorials were probably too long (around 25–30 minutes). We estimate that the average tutorial took 1.5–2 hours to create and publish, i.e., approximately one hour to create the

example problem (and confirm its solution), approximately half an hour to record the tutorial, and half an hour to upload and publish it. Because the majority of the video tutorials involved a problem formulation and solving the formulation using software, we often used screen recordings. Specifically, we used QuickTime (http://www.apple.com/quicktime/) to record the screen and our voice as we worked through the example. If you use QuickTime, make sure that you are recording at the "High Quality" setting. Also, make a note that students should view the videos in at least 720p (high definition) and, possibly, in full-screen mode. This will help to ensure that everything that appears in the video can be easily read as the student watches the tutorial.

Long-Term Impact of the Video Tutorials Outside the Classroom: In their responses, some students stated that they have used the video tutorials as quick refreshers in completing work in other classes (e.g., formulating integer programs for help in their supply chain course). We believe that, given the accessibility and availability of the video tutorials, they are more likely to be used than a textbook in the future (especially given that most students sell back their textbooks). This future use could include tutorials to help with projects throughout student careers. In addition, students stated that they enjoyed controlling the video tutorials at their own pace including being able to pause and rewind during difficult sections. Therefore, there are potential benefits of video tutorials in enhancing the learning experience for a variety of student backgrounds.

Potential Impacts on Student Workload in the Blended Learning Environment: Although this was not mentioned in any student response, there is the potential for an increased workload in our blended learning environment (i.e., active learning opportunity, presentation of the OR concept, one example of the OR concept, supplemental online example) over a learning environment that presents the OR concept and then two (or more) examples in class to fully understand the concept. This could be a detriment to students who need to see multiple examples before they feel comfortable with the concept. However, we do believe that students who need to see multiple examples would see that the video tutorial is of great benefit since it allows them to proceed with the online example at their own pace. Note also that 86.5% of students who have taken ISYE 4600 have agreed or strongly agreed with the statement "the pace of the course is appropriate" in their end of term evaluations. Therefore, we believe the advantages of our environment outweigh the potential increase in workload.

Some Potential Drawbacks of Video Tutorials: Although the video tutorials were well received by the students, there are some potential drawbacks. The first was that use of the videos created an expectation that *all* material should be covered by a set of video tutorials. Given that we rolled out the current set of tutorials over the course of three years, end of semester students' feedback indicated that there were not enough video tutorials. In addition, there were indications that students expected video tutorials to be available in other courses taught by the first author. This feedback points to the benefits the students saw in using the video tutorials; the drawback is that students expect them to be created. Another potential drawback is that students may be tempted to just view the videos and not attend class.One student stated in the survey that "I knew of students who didn't show up to class who just used the online videos to help them, and they were pretty successful." We believe there is a similar temptation for students to skip class when they are comfortable with the textbook. Furthermore, although we collected no data from semester to semester, there appeared to be no noticeable drop in class attendance as more video tutorials were made available. Therefore, we feel that the opportunities for the video tutorials to create an active learning experience for students who regularly attend class greatly outweigh this potential drawback. Another potential drawback would arise if textbooks were entirely replaced by video tutorials.Students may begin to lose the skill of reading and learning from technical books and other manuals. This could have a negative impact on future endeavors (i.e., during their careers) when they would need to learn from technical reports or manuals.

6. Conclusions

In this paper, we presented the impact of video tutorials on an undergraduate OR course. We presented an overview of the set of supplementary video tutorials created to support this course and discussed how these tutorials can be leveraged to create more active learning opportunities in the classroom experience. In particular, the video tutorials served as an extra example for presenting an OR concept and were replaced in class with students trying to solve an OR "challenge" problem. This allowed students to gain intuition about the concept before its formal presentation.

We discussed the results of an online survey of student perceptions of the video tutorials. In particular, we sought to understand the impact of the video tutorials on office hours, and how student knowledge of the tutorial creator affected the impact of the tutorial. Our results show that students used the video tutorials to answer basic questions about the material and used the office hours to gain a deeper understanding of the concepts and homework. We further learned that the absence of student interaction with the tutorial creator had no impact on the tutorials' effectiveness. This is a particularly important finding because it demonstrates

that our video tutorials can be used in other OR classrooms as long as the tutorials are properly integrated and complement classroom presentation of the material. Our preliminary assessment demonstrated that 12% more students achieved a high mark on the difficult OR concept of the dual relationship between the maximum flow problem and the minimum cut problem. We concluded with a discussion of some of the lessons learned in creating these supplementary video tutorials and suggestions on how to create and/or integrate them into a class.

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Appendix. Full Description of the Video Tutorials

Tutorial 1: (Fall 2012) Modeling and solving a cat's daily menu as an LP: We model planning a cat's daily menu as a linear program. We then discuss how to use the graphical method as a basis for determining the optimal solution. Note that, although this involves planning the cat's menu, it is not a true example of the OR classic diet problem.

Tutorial 2: (Fall 2014) Modeling a bigger Lego workshop example as a linear program: We model a Lego workshop that builds and sells three types of items as a linear program.

Tutorial 3: (Fall 2012) Solving a maximization LP with the simplex method: We solve a linear program with all $\leq$ constraints and an objective function to be maximized using the simplex method. Although we use a spreadsheet to help automate some of the row operations in the Gaussian elimination, access to the spreadsheet is not required to understand the steps involved in the video.

Tutorial 4: (Fall 2012) Applying the two-phase method to a linear program: We apply the two-phase method to a linear program without an easy starting basic feasible solution. We solve the Phase-I linear program and use information from it as a starting point for the Phase-II linear program.

Tutorial 5: (Fall 2012) Modeling and solving a Supermarket Sweep problem as a linear program: We focus on a problem inspired by the game show Supermarket Sweep, which involves filling your shopping cart so that the cumulative value of the items in it is as high as possible. The video discusses how to model this problem as a linear program. We show how to implement and solve the problem with Excel Solver.

Tutorial 6: (Fall 2014) Solving the bigger Lego workshop example using Excel Solver: We implement the Bigger Lego Workshop linear program in Excel Solver by discussing how to format the objective function, constraints, and decision variables in the spreadsheet and how to formulate the linear program in Excel Solver.

Tutorial 7: (Fall 2014) A takeover of the Lego workshop and its role as the dual linear program: We focus on modeling a problem of the takeover of the Lego Workshop (discussed in previous videos) at minimum cost by purchasing the Workshop's resources. We then discuss the role of this linear program as the dual to the workshop LP along with introducing the weak and strong duality concepts.

Tutorial 8: (Fall 2015) How much to pay for more bricks in the Lego Workshop: The role of shadow prices: We determine how much you would be willing to pay to acquire additional bricks in the Lego Workshop example. We discuss the notion of the shadow price of a resource in linear programming and the relationship with the simplex method and duality.

Tutorial 9: (Fall 2012) Applying Dijkstra's algorithm to solve a shortest path problem: We apply Dijkstra's Algorithm to determine the shortest path from an origin to a network destination. The problem was inspired by the song "Meet in the Middle" and helps get a person to the Georgia Pine.

Tutorial 10: (Fall 2014) Applying the augmenting path algorithm to solve a maximum flow Problem: We apply the augmenting path algorithm to determine the maximum flow from a source node to a network sink node.

Tutorial 11: (Fall 2013) Modeling a golf team assignment as a transportation problem: We model a problem of assigning golfers to courses during an invitational tournament as a true transportation problem (i.e., it satisfies all the problem assumptions).

Tutorial 12: (Fall 2015) Applying Prim's algorithm to solve a minimum spanning tree problem: We apply Prim's algorithm to find the minimum spanning tree in a network. In particular, we grow the minimum spanning tree by adding, at each step, the lowest cost arc that connects a node in the tree with a node not in the tree.

Tutorial 13: (Fall 2012) Modeling and solving a farmers market problem as an integer program: We focus on how to solve a problem faced by a farmer in terms of selecting where they will locate their stand over the coming weekend and how they will stock it with apples and pumpkins. We then determine how to solve the resulting integer program using Excel Solver.

Tutorial 14: (Fall 2014) Modeling an auction-based fantasy football draft as a binary integer program: We discuss how to formulate drafting a fantasy football team as an integer program. In particular, we focus on an auction-style draft where each player is assigned a price before the draft.

Tutorial 15: (Fall 2012) Applying a branch and bound algorithm to solve a minimization integer program: We discuss how to apply the branch and bound algorithm to solve an integer program with a minimization objective. We demonstrate the different criteria by which you can eliminate (or fathom) nodes in the branch and bound tree.

Tutorial 16: (Fall 2014) Modeling a monthly budget problem as a goal program: We formulate planning a monthly budget as a goal program. We discuss how to create a linear program in order to model a situation wherein you care differently about deviations from bills, savings, and fun goals.

Tutorial 17: (Fall 2012) Determining the efficient frontier of a call center staffing problem: We determine which workers to employ in a call center during an emergency when there are two objectives, i.e., responsiveness, defined as

a short customer wait time, and efficiency (or utilization), defined as how often employees are working during their shift. We present a method to construct the efficient frontier for these objectives by solving single-objective problems.

Tutorial 18: (Fall 2013) Double Dare and decision trees: We focus on deciding whether a team in Double Dare should pass the question to the other team and, if it is passed back, whether to answer the question or take the physical challenge. We discuss how to use the decision tree to determine the correct sequence of decisions for this uncertain environment.

Tutorial 19: (Fall 2014) Deciding the top pick in a draft with decision trees and expert predictions: We focus on helping a football team determine their top pick in the upcoming draft. We determine whether it is worth considering hiring an outside draft expert to evaluate the teams candidates (if you are familiar with the teams draft history of offensive players, the answer is obvious) and then using a decision tree to determine the best course of action for the team.

Tutorial 20: (Fall 2013) Modeling Chutes and Ladders as a Markov Chain and its steady-state probabilities: We model a small scale Chutes and Ladders game (that goes on forever) as a Markov Chain. We discuss the states of the Markov Chain, the transition probability matrix, and formulate the steady-state probability equations. We solve this set of equations to determine the long-run percentage of time the Markov Chain spends in each state or, equivalently, the long-run percentage of time a player is on a particular space.

Tutorial 21: (Fall 2013) First passage times and the Chutes and Ladders Markov Chain: We determine the expected first passage times of various states in the Chutes and Ladders Markov Chain.

Tutorial 22: (Fall 2014) Modeling a golf hole as a Markov Chain and using absorption probabilities to analyze scores: We model playing the 17th hole at The Players Championship (TPC) Sawgrass (the famous island green) as a Markov Chain with absorbing states. We discuss how to formulate and solve the equations associated with ending up in a particular absorbing state to determine the likelihood of making par or better on the hole.

Tutorial 23: (Fall 2015) Modeling a market share and advertising problem as a Markov Decision Process: We model the market share of a company and its advertising decisions for each state as a Markov Decision Process (MDP). We then formulate a linear program in order to solve the MDP and help determine the optimal advertising decisions for each state of the underlying Markov Chain.

Tutorial 24: (Fall 2014) Applying Little's Law to a new stadium screening procedure: We model a new stadium screening procedure (similar those for getting to airport gates) as a queuing system. We then apply Little's Law to understand the key system properties including the average amount of time a fan spends in line.

Tutorial 25: (Fall 2012) The I Love Lucy chocolate factory as a queueing system: We analyze the I Love Lucy Chocolate Factory scene as a M/M/s/K queueing system. We discuss how this system is a birth and death process and then apply an approach to determine the key parameters of the queueing system including the average number of pieces of chocolate waiting to be wrapped, hidden or eaten and the average time a piece of chocolate spends on the production line in front of Lucy and Ethel.

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