Docendo Discimus: Students Learn by Teaching Peers Through Video

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ABSTRACT

This study presents and evaluates a scalable approach for improving learning outcomes by having students "teach" peers in the same course via video. The approach was tested in a standard upper-level undergraduate computer algorithms course with material commonly considered challenging to teach: combinatorial optimization and NP-complete problems. An important design goal was to incentivize students to learn deeply in crafting their instructional videos while minimizing the added burden on instructors to review their products, allowing for scalability. A learning assessment administered to two successive cohorts (N=89) showed statistically significant improvement ($P < 0.0001$) in learning for students who make the videos compared to those who merely study the materials or view the videos. Students not only enjoyed applying their creativity in making videos but, in the process, also strengthened their conceptual learning. While much of the existing research on student-created videos has shown its effectiveness in motivating students, few studies exist that directly isolate learning gains in those who *craft* instructional videos.

KEYWORDS

Active learning; Student-centered learning; Student-created videos; Improved conceptual learning; Scalable Instructional resources; ACM proceedings; SIGCSE

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1 INTRODUCTION

The notion of learning by teaching can be traced back to the Latin phrase *docendo discimus* ("by teaching, we learn") attributed to the Roman philosopher Seneca the Younger (4BC – 65AD). Instructors know all too well the experience of acquiring insight while preparing to teach: "the best way to learn something is to teach it." At the same time, getting students to learn by teaching others is fraught with risk: Will they reinforce wrong concepts by teaching them? Will they take the task seriously enough to go deep into the subject matter? Who has the time to evaluate their teaching "products"?

The ubiquity of smartphones and of free and simple editing software makes the cost of crafting video extremely low. This offers an opportunity for a scalable approach in which students make videos that "teach" a topic, which can then be peer-studied in a manner similar to peer-graded writing. The trick is to design a protocol that has the right incentives to address the risks mentioned above. The goal of our project was to design and evaluate such a protocol, which has now been refined over two semesters. A learning assessment (a quiz) showed statistically significant gains in learning when applied to a module of an upper-level undergraduate algorithms course. The video assignment was one of many assignments in the course but the only one to focus on the topic of combinatorial optimization and NP-complete problems.

The protocol can be summarized as follows (details are given in Section 3). Students are placed in teams; each team is assigned a topic and tasked with crafting a video that explains the topic along with a number of required contextual aspects. Each student, independent of the video production team to which they are assigned, is also given a second topic to *study*. The "studiers" are given links to text material and required to watch the video produced by the team assigned their second (study) topic. Students under the production and study treatments are incentivized to learn the material to do well on a quiz, but if the docendo discimus theory holds, producers should do better. Furthermore, we expect producers to do better on the conceptually harder questions in the quiz.

The contributions of this paper are:

- The design and evaluation of a scalable protocol for engaging students to learn by teaching.
- Addressing incentives for students so that they put sufficient effort into their assignment both as producers and as studiers.
- A small learning study (N=89) that provides evidence supporting the approach.

Prior studies that examine the effectiveness of video in learning have focused on instructor-created videos [2, 3]. While some have examined student-generated videos, these tend to focus on either motivation or overall learning in the course, making it difficult to tease out the "I learned something deeply because I had to teach it" effect. Our study focused narrowly on this effect with statistically significant evidence in support of the approach.

Students received and carried out the project enthusiastically. This too aligns with studies [10, 11, 17, 21] that show greater student engagement with video and media, as well as studies that show

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increased engagement when students are given autonomy and opportunities to be creative [5, 27, 31].

2 RELATED WORK

Student-produced objects, and videos in particular, have been the subject of increased focus in pedagogical research. This is due in large part to the rise of active learning techniques and the growing accessibility of cheap recording and editing methods.

2.1 Student engagement

Kearney and Schuck [13] focused primarily on student and teacher perception of the potential of student-generated video to enhance the learning experience, particularly in the area of *authentic learning*, which they define as "learning in ways that fit with real world contexts". They found that the video projects helped motivate students, particularly if they knew that their classmates would be the target audience. In two follow-up studies [14, 27], they found clear evidence that student-generated video projects strongly enhanced their motivation and autonomy, and that allowing them to present in their own style, and the feeling of ownership this produced, were key factors in enhancing the learning process. They highlight the need for a well-designed project and the importance of the instructor's guidance when discussing the contents of the student presentations.

Several other studies found clear support for the benefits of student-produced videos on motivation, self-confidence, and engagement, and that they promoted the acquisition of technical and communication skills [5, 10, 11, 21]. Chi et al. [4] present empirical evidence of increased learning across four modes of learning activities and engagement behaviors:*interactive, constructive, active, or passive*, Under this framework, a team activity aimed at video production would appear to fall under the highest learning level.

While these studies demonstrate an overall improvement of student experience and the indirect learning benefits that come from student-produced videos, a key finding in some of these studies was a low level of conceptual development [27]. In the same vein, Pirhonen et al. [21] report a lack of evidence for improved learning.

2.2 Assessment

Another area of focus has been the use of the video-project as an assessment mechanism. This was mentioned in the work by Kearney and Schuck [27] as a key part of assessment strategies. An in-depth study by Murray et al. [18] determined, through the use of surveys, that the majority of students preferred video assessment over traditional methods like exams or reports. They underline the importance of having the instructor moderate any type of peer assessment to prevent any anxiety that might arise because of the prospect of judgment from their classmates. Walters et al. [29] implemented an assessment protocol using student videos, where they determined that it was an acceptable and even "pleasing" assessment method. They concluded that the effectiveness of learning environment can be enhanced by multimedia technology when using a learner-generated approach.

2.3 Improving conceptual learning

Studies disagree on whether or not student-produced videos promote an actual improvement in conceptual development. Little or no evidence was found in [21, 27]. Another study where this is supported is in the work by Draus et al. [6] where, despite there being an increase in perceived value from learned content, no measurable difference in student outcome was detected. On perceived value, Ryan et al. [26] report that students were uncertain about the effectiveness of the video projects on their learning.

On the other hand, in the work of Box et al. [1], they found small-to-large effects on the number of correct responses for laboratory quizzes. Willmott et al. [31] found statistically significant increase in scores of self-evaluation surveys measuring perceived improvements on learning. In the work by Brecht [2], it was determined that videos were used as tutorials, and that their application in classrooms improve initial learning, reduces dropout rates, and has a positive impact on course grades. Walters et al. [29] found that, when using video projects as an assessment tool, there was a substantial increase in passing grades as compared to written examinations. Greene et al. [11] found, through the use of surveys, that creating videos helps students reinforce concepts they have been exposed to in class. Roscoe et al. [23, 24] argue that two key activities to take advantage of knowledge-building opportunities are *self-explanation* and *peer-questioning*. A properly constructed team-based video-creation protocol would promote both of these key activities and contribute to conceptual learning.

2.4 Areas of application

The technique of having students create tutorial videos has been successfully applied in several areas, like history, science, language, media studies, marketing, distance learning, and more [6, 16, 27]. While some areas and classes lend themselves naturally to video presentation, others, like computer science and mathematics might appear to focus on subject matter inimical to this medium. This is not so, as evidenced by the work of [1, 15, 17, 18] which show clear positive effects of student-created projects in the areas of mathematics, aerospace engineering, information technology, and organic chemistry, respectively. In the work by Nordstrom and Korpelainen [19], it was pointed out that non-conventional tools like video can promote deep learning of scientific facts. For an in-depth report of active learning as a positive influence in science, engineering, and mathematics, see [8].

Student-produced videos may constitute a reusable peer learning resource [22, 26, 27]. While some content might not age well, the concepts taught in STEM courses are less likely to change over time due to the largely consistent nature of the material they present, which makes a large stock of conceptual videos a very useful long-term resource.

There is research supporting the use of active learning in computer science [8], and even the use of video-lectures as a valid resource [20], but there seems to be little work devoted to the effect on conceptual learning of student-produced video presentations in computer science. One of the few studies that looks into the use of videos in CS is the work by Gehringer and Miller [9], where they found an increase in student attentiveness, rather than increased conceptual learning.

3 METHODS AND EXPERIMENTAL DESIGN

3.1 The course

The video project was implemented in two successive offerings (2015, 2016) of an upper-level semester-long undergraduate algorithms course that featured both theory and programming. The course topics are fairly standard: searching, sorting, advanced data structures, graph algorithms, dynamic programming, combinatorial optimization, NP-complete problems, along with a few advanced topics. The course pedagogy included lectures interspersed with active-learning exercises, followed up with reinforcement through weekly homeworks and assignments. It is one of these assignments, focused on the topic of combinatorial optimization problems, that we reformulated for the video project.

3.2 Specific goals for the study

We designed this study with several specific goals in mind. First, we sought a scalable approach to allow its application to large classes, requiring modest additional effort on the part of the instructional team. Second, we wanted to devise a quiz that would measure whether students that produced a video demonstrated a significant improvement in the understanding of complex concepts. Third, we were also interested in finding a suitable way to exploit the potential of teamwork, especially in the crafting of videos.

3.3 The video-assignment protocol

At a high level, the following steps describe our approach.

- Students are divided into teams of three. In our case, we typically had 30-50 students per class.
- The instructor selects subtopics and assigns one subtopic to each team. We assigned a different NP-complete problem of similar structure and subject matter to each team.
- The instructor designs one assessment per subtopic, ideally with at least one challenging question to tease out whether the video-producing team really dug into the topic. This part is the most time-consuming for the instructor, but only needs to be done once and can be reused for future offerings.
- Each team is then given their subtopic and asked to produce an explanatory video that satisfies a list of criteria (which we describe below).
- Separate from the teams, each individual student is given one of the subtopics to *study*, ensuring that no student is given the same topic for both production and study. Thus, each subtopic has a producer and some "studiers." For any given subtopic, we provide links to reading materials for both producers and studiers. Conveniently, in our case, Wikipedia has a page on each NP-complete problem.
- Students are given a week to produce their videos. We also told students that they had to describe their sources (in an accompanying document), and to explain how each team member contributed. We informed them that, should it prove necessary, we would reserve the right to question any team member on any aspect of the video.
- After the videos are crafted, they are made available to the studiers. Everyone is asked to study both from the materials and the video for their assigned "study" subtopic.
- Finally, each student takes two quizzes: the first quiz is on the subtopic of their *production* while the second is on the subtopic of their *study*.
- Team points are assigned for the quality of video production, while individual points are given for performance on the quiz. This creates an incentive to spend enough time on crafting the video because the producing students realize that they can optimize by digging deep into their subtopic both for production points and study points. They also have an incentive to study for their assigned study subtopic.

All but two of the steps above scale with class size. The exceptions are the one-time effort needed for devising the quizzes, and the time needed for grading the videos. In the former case, several different teams in a large class can be assigned the same subtopic, perhaps with care taken to avoid publicizing which team is assigned which subtopic. For the latter, if instructional resources are not sufficient for video review, one could opt for peer-review of videos (each student is assigned some videos to review with a criteria-satisfying rubric), or use undergraduate learning assistants from students who have taken the course before.

In developing criteria for video production, we sought to achieve a balance between encouraging self-expression and originality, on the one hand, and avoiding confusion and wasted effort on irrelevant video effects. Prior work has highlighted the importance of this balance [21, 22, 27]. In particular, we wanted to avoid making the video project about learning new media skills. We therefore opted to let the students choose the method in which they recorded and presented the videos, as long as the following basic criteria were met:

- The video must contain a technical description of the problem as well as an explanation in plain English.
- A concrete example must be completely explained and solved.
- In addition to the formal technical explanation, the video should explain the application.
- The audio, video, and effects must be clearly understandable.
- The video must be no more than 10 to 15 minutes in length.

A duration of 10 to 15 minutes constitutes a reasonable compromise that allows for content completeness without risking a decrease in engagement and attention [12]. It also facilitates evaluation, since the videos have clear sections and a reasonable duration. In sum, this protocol is in alignment with principles on student-produced videos described in the literature [5, 13, 21, 27].

3.4 Design of study

The study was carried out in the 2015 and 2016 Fall semesters, with 39 and 50 students respectively, for a combined N=89 students. The NP-complete problems selected as subtopics were chosen to have a similar degree of complexity and so that each had an understandable application. Thus, problems like traveling salesman make sense whereas something in timed petri-nets would be too theoretical and require significant background.

Before being distributed to the studiers, the videos were reviewed for satisfying the criteria. A simple checklist was used for this purpose. In our study, all but a few submissions passed this step. For those that did not, students were given specific notes on any issues and how to address them before resubmitting. We did this so that there would be a level playing field for all the studiers.

Students were given the same number of days to study their assigned "study" subtopic as they were given to make a video for the "production" subtopic. Once available, students were given two days to study the video for their "study" subtopic (which was produced by another team). In accordance with the protocol, each student took two quizzes, the first on the subtopic assigned for production and the second on the subtopic assigned for study. Note that every subtopic was assigned as a production subtopic for one team, and assigned as a study subtopic for a different set of 2 or 3 students.

Each quiz consisted of four questions designed to gauge the level of understanding of the specifics of the problem and the context in which it was studied. It is very important to mention that all quizzes were designed to ask about the technical and high level concepts in the same way for all different subtopics, thus ensuring that no particular topic was more challenging than another.

Question one in each quiz was especially designed to assess deeper technical understanding. An example of one of the quizzes can be seen in Figure 1, in which the first question is the hardest one. Note that all the choices for this question contain language and terminology used in the correct definition of the problem, but only one does so correctly, and some of the others are deliberately misleading. The nature of the description is somewhat technical, so that only someone who understands the problem well enough can see the equivalence between the technical description in the choices and their assigned subtopic.

The second question relates the problem to the general area of combinatorial optimization. This requires the generalization of the elements of the problem as well as integration with the previous lectures on problem complexity and related categories of algorithms and problems. This is a free-form question in which three specific requirements need to be clearly stated for the answer to be complete. Partial credit was awarded.

Question 3 requires that the student understand the particulars of the problem scenario, as well as its possible application to an actual problem. This is a free-form question in which students may relate any examples presented in the video that explained it, or create a new problem instance from what they have learned. Partial credit was awarded.

Question 4 is another free-form question where the student is asked to pose a possible real-world application of the concepts surrounding the problem.

Questions 3 and 4 require the least amount of detailed technical knowledge, but both require the student to contextualize the concepts, reinforcing what Kearney and Schuck call *authentic learning* [13].

Data analysis consisted of gathering the per-question grades from each of the (N = 89) students in the *produced quiz* (taken by those who produced for that subtopic) and the *studied quiz* (taken by those who studied for that subtopic). These constituted a collection of paired samples of four questions per student.

In all but the first question, the Wilcoxon signed paired test [7] was used to statistically analyze the paired samples of the final grades. To implement the test, we used the *stats* package in R [28].

(1) Which of the descriptions below comes closest to describing the problem you were assigned?
  (a) Suppose U is a set of points $(x_1, y_1), \ldots, (x_n, y_n)$ in the plane. For each pair of points in the set, define the midpoint as the point exactly halfway in between. Any midpoint that's at most distance W from its end points is called a center, where W is a given bound in the problem. The goal is to compute the centers.
  (b) Suppose U is a set of points $(x_1, y_1), \ldots, (x_n, y_n)$ in the plane, and V is another set of points $(a_1, b_1), \ldots, (a_m, b_m)$. For each point x_i, y_i in U and a_j, b_j in V, let $d(i, j)$ denote the distance between the two points. For each such pair, let p, q denote the point halfway in between (the midpoint). We'll call this the center. The goal of the problem is to compute the centers.
  (c) Suppose U is a set of points $(x_1, y_1), \ldots, (x_n, y_n)$ in the plane, and V is another set of points $(a_1, b_1), \ldots, (a_m, b_m)$. A point p in the set V is called a center, if the distance from every point in U to the center is less than some given number W. The goal is to identify which of the points in V are centers.
  (d) Suppose U is a set of points $(x_1, y_1), \ldots, (x_n, y_n)$ in the plane, and V is another set of points $(a_1, b_1), \ldots, (a_m, b_m)$. For any point $p = (x_i, y_i)$ in U, let $f(p)$ denote the closest point in V to p, and $d(p)$ be the distance between p and $f(p)$. Define $D = \max_p f(p)$. The goal of the problem is, given a set U with n, find a set of m points V to minimize D.
(2) Explain how your problem is a combinatorial optimization problem. That is, explain why it satisfies the three requirements.
(3) Create an instance (example) of your problem, with a drawing or illustration where needed. Show a couple of candidate solutions where one solution is better.
(4) Write down a potential application for your problem.

Figure 1: Example quiz (Euclidean p-center problem)

To measure effect size, we use the standard z-score approximation [25] to Cohen's d measure: $d \approx r = \frac{z}{\sqrt{N}}$

Because Question 1 is scored either right or wrong, we use the McNemar test with Yate's continuity correction for binary paired data. This is performed using the *gmodels* package in R [7, 28, 30]. For the McNemar test, the conditional odds ratio $OR = \frac{c}{b}$ is used in place of an effect size, where b and c are the number of discordant pairs i.e., those where a negative or positive change occurred between treatments, respectively.

4 RESULTS

For the overall grades, as well as for questions 1−3 seen individually, there was a statistically significant improvement (those marked with a ∗) when going from the study to the production treatment. A summary of results can be seen in Table 1. Because Question 1 is binary, its results are analyzed separately. Given that these are paired tests between the video-production and the study treatments, the data can be arranged by the change from one treatment to another. The paired results can be seen in table 2.

Table 1: Summary of results

Question	Test	Statistic	P	effect size
1	McNemar	6.283	0.0061∗	0.44
2	Wilcoxon	978	0.001∗	-0.35
3	Wilcoxon	677	0.03337∗	-0.23
4	Wilcoxon	22	0.57	NA
Full	Wilcoxon	705	<0.0001∗	-0.43

Table 2: Q1 Contingency Table (numbers represent pairs)

		Produced		
		Correct	Incorrect	Total
Studied	Correct	a=26	**b=14**	40
	Incorrect	**c=32**	d=17	49
	Total	58	31	89

For the first question, the ratio of correct responses went from $40/89 \approx 45\%$ to $58/89 \approx 65\%$, with an odds ratio of $OR = 0.438$. A student that prepares for Question 1 by producing a video has his or her odds of getting a correct answer increased by 44%. For Question 2, we found a statistically significant improvement ($P = 0.001$) from the study treatment (median of 90%, mean of 78.5% with a $SD = 25.9\%$) to the video production treatment (median of 90%, mean of 85.5% with a $SD = 21.9\%$) and an effect size of $r = -0.349$, which is considered to be a small-to-medium effect size. In Question 3, we found a statistically significant improvement ($P = 0.03337$) from the study treatment (median of 100%, mean of 83.4% with a $SD = 27.2\%$) to the video production treatment (median of 100%, mean of 88.7% with a $SD = 22.4\%$) with an effect size of $r = -0.225$, which is considered to be a small effect size. In Question 4, we found that there was no statistically significant improvement between treatments.

When looking at the overall grades, we found a statistically significant improvement ($P < 0.0001$) from the study treatment (mean of 75.5% with a $SD = 20.9\%$) to the video production treatment (mean of 84.1% with a $SD = 16.3\%$) with an effect size of $r = -0.429$, which is considered to be a small-to-medium effect size. The Box plots for questions 2, 3 and the full quiz can be seen in Figure 2. A boxplot for Question 1 is not included because the data is binary.

The type of question plays a role in the magnitude of the improvement that was obtained. Figure 3 shows the improvement obtained per question.

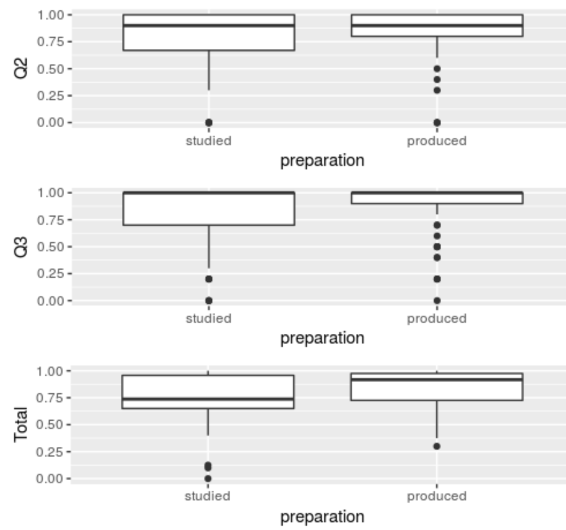

Figure 2: Box plot for Questions 2, 3 and the overall grade

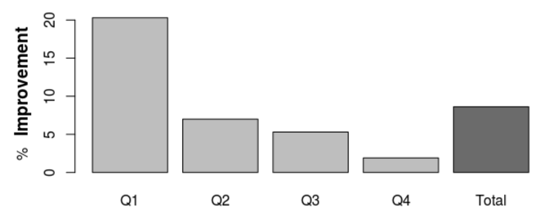

Figure 3: Grade improvement per question

5 DISCUSSION

By design, Question 1 required the deepest knowledge of the problem. The distractors (wrong choices) were very similarly worded so that choosing the wrong option was likely if students were hazy on the details of the problem and the interplay of its parts. The fact that it was graded as all-or-nothing meant that the effect this question had on the overall quiz grade was large. It is important to consider this possibility of confusion when considering the results of Table 2. Many of the possible errors might come from simply misreading the options. Even when considering these type of errors, the increase in the ratio of correct answers, as well as the fact that we are considering paired samples, allows us to conclude that there is a clear improvement in the student performance while under the video production treatment.

The remaining questions were considered to be easier because it was possible to get a fair amount of partial credit by being able to contextualize the problem and relate it to real-world scenarios. Questions 2, 3, and 4 move away from the details and into high level understanding of the problem in its context. Students had a much easier time doing those, which is evidenced by the high medians obtained in these questions (100% in both studied and produced treatments). In all but the most general question (Question 4), a clear advantage was noticed for those students that produced a video. It is worth noting, that for questions 2, 3 and for the full quiz grade, the quantiles are tighter for produced-video treatment. This points to more consistent results for producers than for the study treatment. We believe that group work plays a part in this reduced grade variance. One explanation for this effect is that, along with the positive effects on individual performance, collaboration provides an environment in which to compare and corroborate ideas, which reduces the possibility of maintaining misconceptions and hazy notions. A higher and closer grade range also opens the possibility of using the group average as a grade for all students, which could potentially motivate a fair division of work, and allow for the application of this protocol to larger teams.

We think that the reason that Question 4 showed no improvement between treatments is due to the fact that it was the most general question and it allowed for basic/general knowledge of the problem to result in a greater chance of a high grade.

Thus, *students do considerably better when producing a video*, according to the data. We think that this is because the production of the instructional video requires the grounding of a multitude of concepts as well as their integration into a wider theoretical context, which aids in the understanding of the particulars with respect to the whole as well as providing a framework for the memory to retrieve details with greater precision. It is worth mentioning that the effect size is consistent with those published in earlier meta-analyses in the area of active learning for sciences, engineering and mathematics [8].

6 CONCLUSIONS AND FUTURE WORK

This study found statistical evidence to support the claim that student-produced videos provide significant improvements in terms of learning retention, contextualizing, and applying of theoretical concepts in the field of computer science. We also noted that there was less variability in response qualities for both specific and context-related questions.

A careful description of the project, as well as continued guidance is important to maintain video-content correctness and quality. We found that allowing students to express themselves through various modes of presentation and styles did not hinder the effort, and in fact, might have made the whole experience more memorable. This has the added benefit that a large amount of tailor-made stock footage of good quality can be accessed by future classes. The protocol described here can be replicated with very little overhead because most of the required knowledge and equipment is provided by the students themselves. This allows for a scalable procedure that can improve student engagement and attitudes, and has a considerably positive effect on the quality of the initial knowledge retention and its relation to the theoretical context.

Since this protocol is group-based by design, in the future, we would like to differentiate the production of videos from the precise effects of team collaboration on improvement. Additionally, we would like to refine the protocol to further tighten intra-team variation. Lastly, we would also like to explore the long-term benefits of this approach by surveying previous generations.

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