Video making as a powerful tool in physics teacher education and in teaching and learning

M MILNER-BOLOTIN¹, I TAKÁTSNÉ LUCZ²

¹Department of Curriculum and Pedagogy, University of British Columbia, 2125 Main Mall, Vancouver, BC Canada V6T 1Z4
²Doctoral School of Physics of Eötvös Loránd University, Pázmány Péter sétány 1/A, 1117 Budapest, Hungary

Abstract. This paper describes the results of the international research collaboration on educational science video making between the researchers at The University of British Columbia in Vancouver, Canada and Eötvös Loránd University in Budapest, Hungary. In this study, future physics teachers designed short YouTube-style educational videos showcasing their own physics experiments. We examined how pre-service physics teachers acquire their pedagogical demonstration skills while also becoming amateur video producers, and how these videos can be used to deepen students’ physics knowledge, stimulate their curiosity and consequently increase their physics engagement, interest, and motivation. Secondary school students’ feedback and the results of their pre- and post-tests also provide evidence that thoughtfully designed educational science videos can be effective in supporting student independent learning.

1. Introduction
Science visualizations and demonstrations play a key role in teaching physics as its laws and theories are firmly rooted in empirical evidence. Thus, science experimentation lays at the core of physics teaching, as it can help illustrate or verify scientific principles and lead students to a deeper understanding of abstract physics concepts. This project focused on the basic experiments relevant to the secondary physics curriculum. Particular attention has been paid to the experiments requiring limited special equipment that could even be performed at home. The aim of this study is to investigate pedagogical interventions that can help improve future physics teachers’ (FPTs’) experimental and pedagogical skills and create a collection of research-based pedagogical resources (video experiments) which could be used during their school practicum or consequent teaching. Moreover, the secondary school students’ learning through the use of online resources, such as science videos, and the effects of different pedagogical approaches that incorporate educational videos were also investigated [1].

In recent years, the use of educational videos has become widespread in secondary and post-secondary physics classrooms [2, 3] and in science teacher education [4, 5]. By relying on the visual
and verbal-processing channels for information acquisition, educational videos can maximize students’ learning and facilitate their active engagement with the content [5-7]. Integrating videos into physics lessons has additional advantages. The videos can be (a) paused and replayed at any time and place the students want; (b) the diagrams and graphical representations can be overlaid on the experiments, thus helping students use multiple representations to describe the phenomena under investigation; (c) students can use the videos both in or outside of class, thus increasing access to science experiments; (d) the videos can be coupled with computer simulations or other tools, allowing students to use multiple representations to make sense of physics [8, 9]. Posing guiding questions before watching the videos or embedding the tools into the videos, using signalling, highlighting the key information can help direct learners’ attention to the most important information enhance students’ learning experience is an additional way to make these resources an active learning tool in physics.

In this research, we studied the engagement and the pedagogical growth of FPTs as the result of designing physics demonstrations videos during their physics methods course in their teacher education program. To keep secondary students engaged and hold their attention while watching the videos, they had to be between 5-10 minute-long and use a conversational style in the explanations. The videos also had to be carefully edited to use scientific terminology familiar to the students, to incorporate student prior knowledge and connect the phenomena of interest to students’ lives, as well as use multiple representations to shed light on the demonstrations [10].

These videos can be used both in the traditional class and in the flipped classroom environments. In the first case, watching them will take only a few minutes and the experiences will be fresh. This is especially valuable when the teacher cannot perform these experiments during class with the students. While in the second case, the teacher can save some time by asking the students to watch the videos prior to class and starting the lessons right away with discussing the issues that arose from these videos. No doubt these videos are not intended to substitute for the live experiments performed during face-to-face physics lessons. However, for various reasons (and COVID-19 pandemic is only one of them), performing all these experiments with the students might not be always feasible. These videos can also supplement in-class instruction and generate a fruitful discussion to help students make sense of the abstract science concepts. Furthermore, it is also well-known that many schools around the globe have limited financial resources to maintain and develop their laboratories, so this video-channel can be a recommended tool to help schools that are dealing with this problem. It can also be useful for creative teachers to inspire them to design similar videos for their own face-to-face lessons. As most of the experiments presented in the videos do not use any special equipment students can perform them safely at home, so they can become active members of the learning process. Moreover, during these activities the students can slowly start building their experimental skills are generate new questions they might want to discuss with their peers and teachers.

To summarize, the aims of our project are threefold:

1. **For FPTs:** To engage them in designing educational videos and experiencing first-hand hands-on science teaching and learning in order to improve their experimental, pedagogical, and science communication skills;
2. **For secondary physics students:** To awaken their curiosity, when they are grappling with new and complex physics concepts, and to increase their physics engagement and motivation;
3. **For physics education researchers:** To collect empirical evidence regarding the pedagogical effectiveness of these videos as a resource for independent learning of secondary students.
2. Methodology

2.1. Project history

It began in 2010, when the first annual Family Math and Science Day (FMSD) – an open-house hands-on STEM (Science, technology, engineering and mathematics) event for the general public led by future science teachers was hosted by the University of British Columbia (UBC) Faculty of Education [11]. Our aim was to support future teachers in developing confidence in communicating STEM, teaching them how to design and perform demonstrations and activities which require simple equipment. They could also test dozens of safe hands-on activities mentored by their course instructors. While it was challenging to engage such a diverse audience in STEM but the high level of satisfaction from the event made it all worthwhile. Since then, due to the high level of interest eight annual FMSD events have been organized by the UBC and were only interrupted by the COVID-19 pandemic. One of the outcomes of the FMSD was FPTs’ desire to collect and share successful demonstrations performed during the day so they can be used during the school practicum and consequent teaching. This motivated one of the authors (MMB) to begin STEM Education Videos for All YouTube Channel [10].

2.2. First stage (UBC)

In preparation for the annual FMSD, FPTs teachers were asked to collaborate with peers during a physics methods course to design and present in class a short physics demonstration. After receiving peer and instructor feedback, FPTs recorded the videos of their experiments and augmented them with the pedagogical descriptions, additional relevant information, as well as emphasized connections of these experiments to the curriculum, everyday life and other subjects. Then FPTs uploaded their videos on a specially designed YouTube channel [10]. Videos had to be presented in a manner such that secondary school students could understand the physical principles these experiments were supposed to illustrate. To help FPTs design the videos, a few example videos were created by a research team, including the template, musical background, etc. Project guidelines were also created and a special video making workshop was held. Currently, the collection features more than 80 videos and has been visited by thousands of viewers from around the world.

2.3 Second stage (ELTE)

The second stage of the study took place at Eötvös Loránd University (ELTE) in Budapest, Hungary. Two topics (Geometric optics and Sound

Figure 1. Family Math and Science Day at UBC.

Figure 2. A screenshot from the students’ favourite video „Natural Frequency & Harmonics”.

Figure 3. A screen shot from “Reflection in a Plane Mirror” video.
and Vibrations) relevant to the Hungarian secondary physics curriculum were selected for the project led by the second author (ITL). Ten relevant physics videos were chosen from the UBC video collection. The screenshots from two of them are shown in figures 2 and 3. The questions for the conceptual understanding test that was administered before and after the intervention were designed accordingly (table 1). For each one of the topics, the test included five different questions. The students had 15 minutes to respond to these questionnaires.

Table 1. Detailed description of the study intervention.

<table>
<thead>
<tr>
<th>Topics</th>
<th>Optics</th>
<th>Vibrations and sound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Videos titles from the online collection</td>
<td>1. Making a light beam visible: Exploring light from a laser pointer</td>
<td>1. Natural Frequency and Harmonics</td>
</tr>
<tr>
<td></td>
<td>2. Reflection and Refraction of Light</td>
<td>2. Sound and Music</td>
</tr>
<tr>
<td></td>
<td>3. An 'alternative' magnifying glass</td>
<td>3. Singing Wine Glasses</td>
</tr>
<tr>
<td></td>
<td>4. Law of reflection: Figuring out the distance between a mirror to a virtual image</td>
<td>4. Frogs in the Lab</td>
</tr>
<tr>
<td></td>
<td>5. Reflection in a Plane Mirror</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6. How optical fibres work</td>
<td></td>
</tr>
</tbody>
</table>

1. Describe the image formed by a plane mirror.
2. There are two arrows on a sheet of paper. We put an empty glass in front of the paper. Try to imagine what will happen to the arrows when water fills the glass. Draw the positions of the arrows in this case into the empty box below.
3. Draw a ray diagram to show the way of light passing through the prism. (The incident ray is perpendicular to the surface of the prism.)
4. Why do we need chalk dust to make a light beam visible?
5. Why does the light ray stay inside the optical fibre? How do we call this physical phenomenon? (This question was included only in the post-test because it would not have made sense to ask it before watching the video.)

1. What are the characteristics of sound? Which physical quantities are they determined by?
2. How does the diameter of a guitar string affect its pitch?
3. What happens to the frequency as the length of the guitar strings increases?
4. How can you change the pitch of a singing wine glass? And the volume?
5. What was the difference between the voice of the mother frog and its daughter frog? Why? (This question was included only in the post-test because it would not have made sense to ask it before watching the video.)
In total, 101 students (14-17-years old) were chosen to participate in this study. They were split into four groups as we describe below. Members of Group 2 were one year older than their peers. Most of the students were at intermediate or upper-intermediate level in English, some of them in Group 1 were beginners. During the student selection process, we had to make sure that students had a sufficient command of English regardless of their prior physics knowledge. It was possible since the study took place in a special secondary school that has two classes in each grade, one with a general curriculum and the other one is bilingual. The students in bilingual classes learn English 27 hours per week in their first school year during their secondary education. At the end of this school-year, they have to pass a First Certificate Exam (FCE). From their second year, some subjects are taught in English (such as Maths, Biology, History, Geography and English civilization). Even though the students learn Physics in Hungarian, most of them didn’t face difficulties following the language of the videos used to introduce physics concepts and principles. Moreover, signalling, the use of on-screen text and diagrams, highlighting the key information were not only tools for keeping the learners’ attention during watching the videos but also helped the students to concentrate and avoid misunderstanding the content. Students participated in this survey were not required to be familiar with the chosen physics topics in order to get a real feedback of the videos’ efficiency for self-directed learning.

Afterwards, the students were asked to fill in a pre-questionnaire based on the videos. Sometimes they had to predict the outcome of an experiment before watching a video, describing it, then they had to answer the same questions after watching the video. We used different pedagogical approaches to determine the most effective way of learning through videos and to keep students engaged and motivated (Table 2).

Table 2. Research design: Four groups experienced different pedagogies while watching the physics videos in class. The intervention ranged from 5-15 min per video as shown below.

<table>
<thead>
<tr>
<th>Group description</th>
<th>Pre-test</th>
<th>Intervention duration</th>
<th>Post-test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Group 1</strong>: Watched the videos together</td>
<td>Five questions related to optics videos</td>
<td>5 min</td>
<td>Five questions related to optics videos</td>
</tr>
<tr>
<td><strong>Group 2</strong>: Watched videos individually on their smartphones</td>
<td>+</td>
<td>5 min</td>
<td>+</td>
</tr>
<tr>
<td><strong>Group 3</strong>: Watched the videos together followed by a discussion with peers</td>
<td>Four questions related to sound and vibrations videos</td>
<td>5 min + 5 min</td>
<td>Five questions related to sound and vibrations videos</td>
</tr>
<tr>
<td><strong>Group 4</strong>: Watched the videos together, was asked guiding questions by the teacher, watched the videos the second time; was encouraged to take notes</td>
<td></td>
<td>5 min + 5 min + 5 min</td>
<td>One question was only asked in the post-test, other nine questions were the same in the pre- and post-tests</td>
</tr>
</tbody>
</table>
3. Results and discussion

All the results of the pre- and post-tests (Table 2) were collected and analysed. Figures 4 and 5 show two examples of the results of students’ responses to the questionnaire questions, where G1 represents Group 1, Q1 represents Question 1, etc.

![Figure 4](image)
**Figure 4.** Students’ responses to conceptual questions on the topic of Vibrations.

![Figure 5](image)
**Figure 5.** Students’ responses to conceptual questions on the topic of Geometric Optics.

The analysis of the results has shown significant improvements in many questions, while the extend of the improvement varied among the groups as shown in Table 3.

**Table 3.** Summary of the changes in student understanding of sound & vibrations topics.

<table>
<thead>
<tr>
<th>Questions</th>
<th>Change in student responses by group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G1 (%)</td>
</tr>
<tr>
<td>Q1</td>
<td>0</td>
</tr>
<tr>
<td>Q2</td>
<td>6.90</td>
</tr>
<tr>
<td>Q3</td>
<td>-6.90</td>
</tr>
<tr>
<td>Q4 (without incomplete answers)</td>
<td>20.7</td>
</tr>
<tr>
<td>Q4 (with incomplete answers)</td>
<td>44.8</td>
</tr>
<tr>
<td>Q5 (without incomplete answers)</td>
<td>31.0</td>
</tr>
<tr>
<td>Q5 (with incomplete answers)</td>
<td>89.6</td>
</tr>
</tbody>
</table>

Tables 2 and 3 show that this type of educational videos can be effectively used to promote student independent learning. Group discussions (in G3 and G4) and guiding questions (in G4) supported the learning process. Students achieved much better results in those groups which were allowed to have a short discussion before the post-test. The best performance happened in G4 possibly due to the guiding questions. Students in G2 generated much better solutions than their peers in G1 due to their better confidence in English.
In order to gain a deeper understanding of the data shown in Table 3, it might be helpful to make the following observations and provide their plausible interpretations.

- There was no significant difference among the groups in their prior physics knowledge. However, Group G3 comprised the most curious and motivated students.
- Most of the students improved their performance as a result of this intervention. Yet, some of the results were surprising. We are discussing them below.
- The negative result on Q2 in group G3 was the most surprising: We can assume that the following could have happened there: a strong physics student misunderstood something and during the group discussion he/she convinced their peers. This was a plausible explanation as it corroborates what was found by others during Peer Instruction discussions, when an influential student convinces peers in the incorrect response [12]. Yet, it was a surprising result because 8 students in this class play guitar and have first-hand music experience.
- Q3, G1: The sound produced a guitar string depends on several factors mentioned in the video (such as tension, length, diameter, linear density, etc.) and the students could not memorize all of them. Those learners who hesitated in the pre-tests but gave a correct answer, might have changed their minds and modified their responses for an incorrect one in their post-tests.
- Q4 consists of two parts one dealing with the sound pitch and another one with the volume. Some of the students answered only one of them. These responses were classified as incomplete answers.
- Q4 (with incomplete answers), G3: 94.4 % of the students gave the correct answer in their pre-tests and 100 % in their post ones.
- Q5 was included only in the post-test as it would not have made sense to ask it before watching the video, as the students were not exposed to this information earlier.
- In Q5, some of the learners produced a proper explanation, but they forgot to answer the original question. Their responses were rated as incomplete ones.

Table 4. Summary of the changes in student understanding of the geometrical optics topic.

<table>
<thead>
<tr>
<th>Questions</th>
<th>Change in student responses on the topic of Optics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G1 (%)</td>
</tr>
<tr>
<td>Q1 (without incomplete answers)</td>
<td>4.20</td>
</tr>
<tr>
<td>Q1 (with incomplete answers)</td>
<td>-4.10</td>
</tr>
<tr>
<td>Q2</td>
<td>25.0</td>
</tr>
<tr>
<td>Q3</td>
<td>83.5</td>
</tr>
<tr>
<td>Q4</td>
<td>33.3</td>
</tr>
<tr>
<td>Q5 (without incomplete answers)</td>
<td>0</td>
</tr>
<tr>
<td>Q5 (with incomplete answers)</td>
<td>20.8</td>
</tr>
</tbody>
</table>

Below we offer our analysis of student responses on the topic of geometrical optics (Table 4).

- As in the previous case, most students have exhibited significant increase in their conceptual understanding as the result of the intervention. We will describe some of the negative outcomes and their probable causes below.
- An incomplete answer in Q1 means that a student did not list as many properties of the image as it was expected (real/virtual image, position, size and distance from the mirror). However, this omission might have been caused not by the lack of understanding, but by the lack of student experiences in describing images in the field of geometrical optics.
- The decline in student responses to question Q1 (with incomplete answers) in group G1 could be explained as follows. Some learners who hesitated and gave incomplete answers in their pre-tests improved but the others made a wrong decision after watching the videos and gave
incorrect responses. There was also an increase in the number of those students who did not give any answer. This might point to the need for additional time needed to support student understanding of this topic. As it has been pointed out before, the topic of geometric optics is fraught with misconceptions and is not as intuitive as one might expect and students require additional experiences and time to gain the necessary understanding [13-16].

- Question Q2 was answered significantly better by G2 after the intervention. This could have been expected.
- Regarding questions Q3: Students in G1 are the youngest learners. They used rulers to accurately draw the path of the light-beam passing through the prism, while the members of the other groups made only a sketch and did not pay attention to the details. Their figures did not realistically reflect even the essential features. Thus, the youngest students provided the most accurate responses.
- Finally, regarding question Q5, which only was included in the post-test: In the top row shown students who not only provided a correct answer, but who also gave the accurate name to the physical phenomenon (total internal reflection). As it can be seen, there were no completely accurate responses in G1 and G2. Only the students in G3 and G4 were able to give accurate answers. This could have been explained as the videos were in English and considering the terminology could have been new to the students, the linguistic barrier probably provided an additional challenge. The second row also includes those learners who could not name the phenomenon, but gave correct answers.

3.4. Third stage

After studying the syllabus and the requirements for the video design assignment in a physics methods course led by one of the authors at UBC, similar instructions for Hungarian FPTs were created in order to help them design their own lab videos which will be tested by their peers at UBC in the future. This part of the project is still ongoing.

3.5. Impact of Video Design Assignment on Future Physics Teachers at UBC

While the study is still ongoing, the feedback from FPT at UBC collected through anonymous end of course student evaluations indicated that the process of designing the videos helped them to feel more confident in being able to engage students in hands-on science, to design experiments on a shoe-string budget. The FPT were especially proud of being able to share their work online with other teachers. They watched and commented on each other’s videos and provided constructive feedback. Moreover, FPT included this experience in their teaching philosophy they had to create before applying for a secondary physics teaching position. Finally, many of them, as well as their peers who didn’t participate in the course used these videos during their school practicum. This indicates that this experience had a positive impact on FPTs’ experiences in the program.

4. Study Limitations

This study has a number of limitations. First of all, the number of FPTs who participated in the study was limited due to the nature of the study. Second, the international collaboration has its own challenges, as teacher education programs in two countries have different structure. Finally, the study is ongoing and we will need to collect more data to see how the videos FPTs designed during their teacher education program are being used both by them, and by other educators. Finally, the bilingual secondary students in Hungary who took place in the study used the videos in English, which might
have made it more challenging for them. While these limitations have to be considered, they do not diminish the value of the findings.

5. Conclusions and future directions

This study has a number of interesting findings for FPTs who designed the videos; for the secondary physics students who used them as learning resources; and for the physics education researchers who study how educational technology might be implemented in teacher education.

For FPTs: We have proposed and piloted a pedagogy aimed at engaging FPTs in designing educational videos and experiencing first-hand hands-on science teaching and learning in order to improve their experimental, pedagogical, and science communication skills. We have shown that FPTs not only learned how to design effective educational physics videos, but also enjoyed the process. We also have preliminary data indicating that designing educational videos helped FPTs to gain confidence in communicating physics in a simple way to their students which would help them in their future teaching careers. This is especially relevant today as the world is dealing with the COVID-19 pandemic and physics teachers are exploring how they can use modern technologies to engage students in physics studies both face-to-face and online. As all these videos are available on the YouTube channel they can serve as a teaching resource for FPTs who designed them, as well as for other novice and experienced educators.

For secondary physics students: We have proposed and piloted different pedagogical approaches that incorporated educational videos of physics experiments in secondary physics classrooms. This pedagogy can be applied to both face-to-face or virtual physics teaching contexts. Based on our experience of testing these videos with the secondary school students in a Hungarian context, we are convinced that the pedagogical approaches we piloted can help spark student curiosity and promote active learning, even when English was not the first language for the students. The physics conceptual gains support the potential of this pedagogy. To maximize student learning, we recommend:

- To make a list of new words and phrases (especially for foreign students) used in the physics videos and review them before watching the videos;
- To ask the students to predict the outcome of the experiments before watching them;
- To provide the learners with the guiding questions related to the video-content prior to watching the video;
- To encourage the students to stop and replay the videos, whenever they feel they might not have understood what they saw. It is advisable to watch the videos in small groups rather than individually, so the students can discuss the videos;
- To encourage the students to discuss what they saw with their peers, to ask questions and to suggest possible explanations.

For physics education researchers: Our study was a multi-faceted collaboration. First, it was a collaboration between Canadian and Hungarian physics educators. Second, it was a collaboration between teacher educators and secondary physics teachers. This is a rather unique opportunity, as we have shown the benefits of this cross-fertilization to both FPTs and secondary students. Third, we have shown how physics educational research can be translated into practice in the context of educational technology implementation both in teacher education and in secondary physics teaching. We realize that we have only scratched the surface of the field of educational technology implementation in
physics education. We hope that more studies exploring how educational videos can be implemented in physics education will follow.

Acknowledgements

This study was funded by the Content Pedagogy Research Program of the Hungarian Academy of Sciences and by the Teaching and Learning Educational Technology Fun at the University of British Columbia, Vancouver, Canada.

References: