University of Tartu
Faculty of Social Sciences
Institute of Education
Curriculum of Educational Technology

Jelena Kosmaca

INTERACTIVE H5P VIDEO EXPERIMENTS FOR AN ONLINE LABORATORY IN PHYSICS

MA thesis

Supervisor: Associate Professor of Educational Technology
Leo Aleksander Siiman, PhD

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Abstract

The work presented in the thesis "Interactive H5P video experiments for an online laboratory in physics" aims to explore technology-assisted learning for online science education. Practical implementation of online video experiments and influence of interactive features added to video on student experiences are investigated. A video experiment with varying levels of interactivity is designed and tested in the study process at university. The collaboration and flow for the 68 participants are analyzed via survey and observations in quasi-experimental research. Findings show that adding interactive features to video can increase student engagement and promote collaboration during online practical works. Cognitive load management and an appropriate collaboration script are identified as key aspects for achieving optimal learning experiences with interactive video experiments.

Keywords: online laboratory, interactive video, H5P, collaboration, flow, student engagement, multimedia learning, hidden profile, cognitive load.

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1. Introduction

Promoting 21st Century skills for students is among the main goals of physics education research (Bao & Koenig, 2019). Problem-solving ability, scientific reasoning, critical thinking, deep conceptual understanding – these are some of the highly demanded competencies that can flourish at the science class with a proper learning environment. Teaching with interactive-engagement elements has long ago been demonstrated as a more effective way for achieving various learning outcomes than only traditional face-to-face lectures in physics (Hake, 1998). Practical laboratory provides an opportunity to acquire reasoning, critical thinking and inquiry skills by active experimenting. This highlights the importance of science education research and justifies why introductory physics courses with a laboratory component are often mandatory in universities and colleges.

Missing hands-on practical laboratory training and lacking well-established approaches for digital learning have been some of the key issues faced in science education during the emergency remote mode due to coronavirus pandemic. Nevertheless, recent casual reports allude to a proportion of students enjoying the flexibility offered by online studies during the pandemics (Ramlo, 2022). In the future, a hybrid or blended approach could become a compromise between entirely online or onsite courses (Mali & Lim, 2021). Having a sustainable remote alternative to onsite learning activities would help meet everyone’s needs and abilities.

Computer-based online laboratory can be a promising solution for science education as an alternative to onsite physical laboratories. In an online laboratory, real experiments are virtualized with the help of digital simulations, pre-recorded or controlled remotely, and students can access them from their computer or phone. Utilizing online experiments can be more cost-effective than maintaining physical laboratory experiments, at the same time accessible and engaging for students. Besides, an online laboratory can also help students prepare for hands-on laboratory tasks onsite, which makes it a sustainable solution for practical classes. Compared to traditional learning activities, the online laboratory is an emerging technology. Recent research has focused on developing new digital learning environments and studying the impact of online experimentation on various learning outcomes (Brinson, 2015; de Jong, Linn, & Zacharia, 2013; Potkonjak et al., 2016).

Video is a suitable and affordable medium for handling online experiments. According to a study on physics laboratory instruction during the pandemic, in 2020, many instructors (79% respondents from more than ten institutions) provided students with videos of prerecorded experiments for remote work, and students reported collecting data from videos in 65% courses (Fox, Hoehn, Werth, & Lewandowski, 2021). In another study, students assessed their remote laboratory performance better when they gather the data by themselves, for example, from video, rather than use digital simulations or ready datasets (Klein et al., 2021). Adding interactive features, such as navigation table of contents, to an educational video could positively influence both task performance (Merkt & Schwan, 2014) and student engagement (Cattaneo, van der Meij, & Sauli, 2018). Preliminary research suggest interactive videos can find applications for physics learning in various contexts (Richtberg & Girwidz, 2019), including short interactive video experiments at university (Laws, Teese, Jackson, Willis, & Koenig, 2017). Studying university learners' experiences with interactive video experiments would be desirable.

This thesis aims to explore application of digital tools in online physics experiments for undergraduate level university students. The research is focused on the design of interactive video experiments and studying their impact on students' collaboration and engagement. Finding designs for interactive video experiment offering optimal experience in remote study mode is an objective of this study. Engagement, motivation, enjoyment, and satisfaction are among aspects of positive user experience with an online learning activity, referred in educational research as *flow*.[1] Therefore, the research question is:

- How do different interactivity features of an online video experiment in physics influence student collaboration and flow?

To answer this question, existing online laboratories and aspects of interactive video experiment technology are reviewed in line with three theories of learning: cognitive theory of multimedia learning, computer-supported collaborative learning, and positive psychology. Three variations of a video experiment, on the topic "Viscosity", with varying levels of interactivity and scaffolding are designed and tested online with 68 undergraduate medical students. Their perception of collaboration and flow during the practical work are assessed and analyzed through a survey and observations in a mixed quasi-experimental research design.

[1] Flow is a mental a state of enjoyment, energetic focus, and creative concentration experienced by people engaged in an activity (Csikszentmihalyi, 2000).

2. Theoretical overview

2.1. Literature review

2.1.1. Traditional hands-on vs. non-traditional online laboratories

Digital tools for science experimentation, such as virtual or remote laboratories, data-sets and analysis tools, can be referred as *online laboratories* (de Jong, Sotiriou, & Gillet, 2014). All these laboratories are implemented through computer-based technology, but there are differences: virtual experimentation is done using virtual equipment (digital simulations); in a remote laboratory, students operate real physical equipment from distance; and for the online data-set case, the experiment has been performed by someone else to provide students with the outcomes to analyze (de Jong et al., 2014). In addition to these, modern experimentation online can be conducted in a mixed approach, for example, via livestream web-conferencing (Petillion & McNeil, 2021). Altogether, these kinds of laboratories can be credited as *non-traditional*, as opposed to *traditional* hands-on laboratories.

The advantages and downsides of traditional and non-traditional (online) laboratories are debatable (de Jong et al., 2013). The value of traditional laboratories is well-established for developing practical skills, learning about experimental errors and troubleshooting. Tactile experience during the hands-on experiments also could foster conceptual understanding (Zacharia, Loizou, & Papaevripidou, 2012). In contrast, virtual experiments often simplify investigation by removing experimental uncertainties and omit most of the tactile experience. Simplification can be useful for learning. Without distractions from physical equipment or time constraints, students could get an opportunity to repeat the experiment as many times as needed and focus on the conceptual aspects. Empirical research has shown that with virtual manipulatives students can learn concepts as well as with physical ones (Olympiou & Zacharia, 2012). Besides, in virtual laboratories extra information can be added to highlight unobservable phenomena. For instance, visualizing electron motion had positive effect on learning outcomes in a virtual laboratory on electrical circuits (Finkelstein et al., 2005). To the date, online (virtual) laboratories have been implemented with mixed success, which depends on the age of learners and the domain. Considering several advantages and drawbacks, a combination of hands-on and online laboratories would be most beneficial for learning (de Jong et al., 2013; Olympiou & Zacharia, 2012).

However, when restricted to an online learning environment, only non-traditional laboratories are an option. For this reason, the effects of online laboratory on various learning outcomes should be thoroughly investigated.

2.1.2. Research trends in online laboratories

A review by Brinson (2015) has analyzed the studied outcomes of learning in traditional and non-traditional laboratories, and grouped them into six categories:

- Knowledge and understanding, the degree to which students model theoretical concepts.
- Inquiry skills, student ability to make observations, hypotheses and experimental designs.
- Practical skills of handling laboratory procedures and equipment.
- Perception, i.e., student attitude and engagement level in the science learning.
- Analytical skills, such as critique and interpretation of the experimental data.
- Social and scientific communication, including presentation of findings and collaboration.

The frequency and results on these learning outcome categories varied among 65 empirical studies included in the review. Primarily the research has been focusing on assessment of knowledge and understanding (95%). Second most studied was perception (53%), with a number of studies evidencing high student engagement level in virtual/remote laboratories. The other four categories were less studied. In particular, the category of social and scientific communication has been assessed in only 5 reports[2] from 2005-2015, indicating a promising research gap to be filled. Overall, majority of the 65 studies suggested that the learning achievement in non-traditional laboratories would be equal or higher than in traditional hands-on laboratories (Brinson, 2015).

The main requirement for an online STEM laboratory is to provide realistic experience close to physical laboratory: "...a student must feel like they are working with real authentic devices in a real authentic space" (Potkonjak et al., 2016). The following aspects are important:

1. User interface with the equipment similar to that in real devices.
2. Behavior and control of the virtual system similar to the physical one.
3. Authentic visualization, which would give students a perception of seeing a real thing.
4. A space allowing communication and collaboration between students and teachers.

[2] Only studies that deliberately assessed communication as an outcome were included (Brinson, 2015).

Analysis of the existing virtual (digital simulation) laboratory projects has demonstrated that almost none of them meet all the criteria at once. In particular, the 2nd and 4th criteria would be difficult to fulfil at the same time. There could be several reasons, such as technical difficulties and costs increasing along with the system complexity (Potkonjak et al., 2016). So, at the present technology development level, virtual laboratories relying on digital simulations are yet to provide us with the feeling of a real laboratory experience. Alternative technologies must be explored.

2.1.3. Interactive video technology

Video is a very popular information medium and an attractive technology for science education. Realistic visualization of dynamic processes makes it a powerful imagery tool for simulating experiences. Thanks to growing technology accessibility and ease of use, almost everyone can record a video and post it on the internet to reach millions of viewers online. Videos are watched not only for leisure but also for learning. For example, a survey of 240 teenage students in Germany showed 65% of respondents subscribed to educational *YouTube* channels related to physics, chemistry, or biology. However, the study revealed also that the watching process is usually passive and lacks active processing necessary for learning (Richtberg & Girwidz, 2019). Active processing could be promoted, for instance, by engaging the viewer with opportunities for navigation and control, like in virtual simulations. A way to improve the existing educational videos would be adapting them into interactive ones.

Interactive video is video that a viewer can interact with, for example, by clicking on active markers appearing on the screen. Once a marker is clicked, an action occurs. In literature, the term *interactive video* is interchangeable with *hypervideo*, which has been described as "..a dynamic artefact, it should allow navigation control and include additional material; it could also integrate individual or collaborative annotation and automated or manual feedback." (Sauli, Cattaneo, & van der Meij, 2018). There can be three kinds of interactive features (Cattaneo, van der Meij, Aprea, Sauli, & Zahn, 2019):

- The control features are enabling temporal navigation through the video. They are usually present in a video player toolbar (play, pause, rewind buttons), but can also appear in the video keyframes as a table of contents or a crossroad pane with a list of clickable timeline hotspots. This offers an opportunity to set an individual pace non-linear learning trajectory.
- Hyperlinks connect the video with additional sources of information in various formats, such as text, images, audio files, web-pages etc. This supports the video content with a

context, details about the topic, and overall promotes an integrated learning environment for better mental model construction.

- Exchange options are enabling communication with others, for example, through text annotations. One of popular exchange options is an embedded quiz feature, which can support peer interaction, reflection and provide immediate (automated) feedback for a learner.

Technically, an interactive video is a raw video with an additional layer of interactive content added in the post-production process. Different computer programs can be used for this. One example of interactive content technology is H5P (an abbreviation for HTML5 Package, www.h5p.org). It is open, free-access, can be integrated in popular Learning Management Systems such as *Moodle* and does not require programming skills, which makes it advantageous for many content creators. Currently available H5P content types include a variety of quizzes, hotspots, memory games, annotation options, etc. Interactive video, course presentation, and branching scenario are among the featured content types on the H5P website.

Branching scenario is made by arranging raw or interactive text, images, presentations and video in a tree with multiple branches and endings. Whilst implementing the scenario, learners must make choices that define the content they will access after the choice has been made. This can be used to create dilemmas, self-paced learning scenarios, and other kinds of adaptive learning. In general, branching simulation scenarios are a promising digital learning approach for medical education because it trains real-time decision-making skill needed for diagnosis and treatments (Pasklinsky, Graham-Perel, Villacarlos-Philip, Slaka-Vella, & Tilley, 2021).

Popularity of H5P among educators is growing. It has been applied for design of various educational content, such as demonstrations and flipped-classroom materials in physics (Chong, Wong, Leung, & Ting, 2019; Richtberg & Girwidz, 2019), a 360° virtual laboratory tour in chemistry (Levonis, Tauber, Schweiker, & Levonis, 2021), virtual simulations in a family assessment course for nursing students (Killam & Luctkar-Flude, 2021). The use of interactive video for practical works seems a promising new niche to investigate. There has been only one very recent case study describing successful application of H5P video for practical works in biomedicine (Unsworth & Posner, 2022). To the best of author’s knowledge, using interactive H5P video for an online laboratory in physics is yet to be reported.

A recent empirical study (Cattaneo et al., 2018) assessing effects of various individual and collaborative hypervideo-based instructional scenarios on student knowledge, satisfaction and flow in practical tasks from vocational education has been an inspiration for this research.

2.2. Theoretical framework

Learning theories elaborate how people acquire knowledge. They must be considered to design teaching materials and investigate impact on the learning outcomes. Instructional design of educational interactive video has implications from socio-cognitive learning theories (Cattaneo et al., 2019). The main concepts from the learning theories selected as grounds for this study are:

1. The multimedia principles from the cognitive theory of multimedia learning.
2. The script theory of guidance from the computer-supported collaborative learning.
3. The concept of flow from the positive psychology learning theory.

The following three sub-chapters discuss in more detail the basics of each of these theories in connection to the interactive video.

2.2.1. The principles of multimedia learning in CTML

Mayer's cognitive theory of multimedia learning (CTML) elaborates on how the teaching material fits the learner's information system (Mayer, 2009). A basic concept of CTML is *multimedia presentation* – a presentation involving words and pictures that are intended to foster learning. Interactive video can be seen as an example of multimedia presentation: words appear in the video in the form of text (annotation) or sound (narration), pictures are either static or dynamic (animation). It must deal with the principles of CTML that are based on three assumptions about the information processing in human brain (Mayer, 2002):

1. Dual-channel assumption is that there are two separate channels for the visual and verbal information in the information processing system.
2. Limited capacity assumption is that only a limited amount of information could be processed in each of the channels at one time, due to the finite capacity of the working memory.
3. Active processing assumption is that both visual and verbal channels must be cognitively loaded for meaningful learning.

Active processing is what differentiates humans from passive processors, such as computer hard-drives or tape recorders. Rather than just storing as much information as possible, humans intend to make sense of the multimedia presentation. To assist with this, multimedia instructions should be designed in a way that they foster active learning. They should have a logical structure and guide the learner to construct coherent mental models (Mayer, 2002).

This can be achieved by managing the three kinds of cognitive load – intrinsic, extraneous and germane. Intrinsic load is caused by the difficulty of the presented material itself, regardless instructional design. It is somewhat subjective, since learning same material might possess different degree of difficulty for expert and novice learners. In contrast, extraneous load is caused entirely by the format of the instruction, it reflects an effort to process a complex combination of words and pictures from the presentation. Germane load reflects learner's effort to create knowledge constructs in long-term memory; it also can be managed by the presentation design. To balance the net cognitive load, the useful intrinsic and germane loads should be maximized on the expense of the counterproductive extraneous load (Sweller, Van Merrienboer, & Paas, 1998).

High cognitive load exceeding the capacity of working memory poses a risk of cognitive overload. This is a common danger for multimedia presentations rich with information. Cognitive overload reducing strategies involve balancing the load on each of the information channels and minimizing extraneous information from multimedia presentation (Mayer & Moreno, 2003). Twelve principles of multimedia learning have been formulated about how to effectively construct multimedia presentation and manage the various cognitive load (Figure 1). Recommendations for effective educational videos adhere with these principles (Brame, 2016).

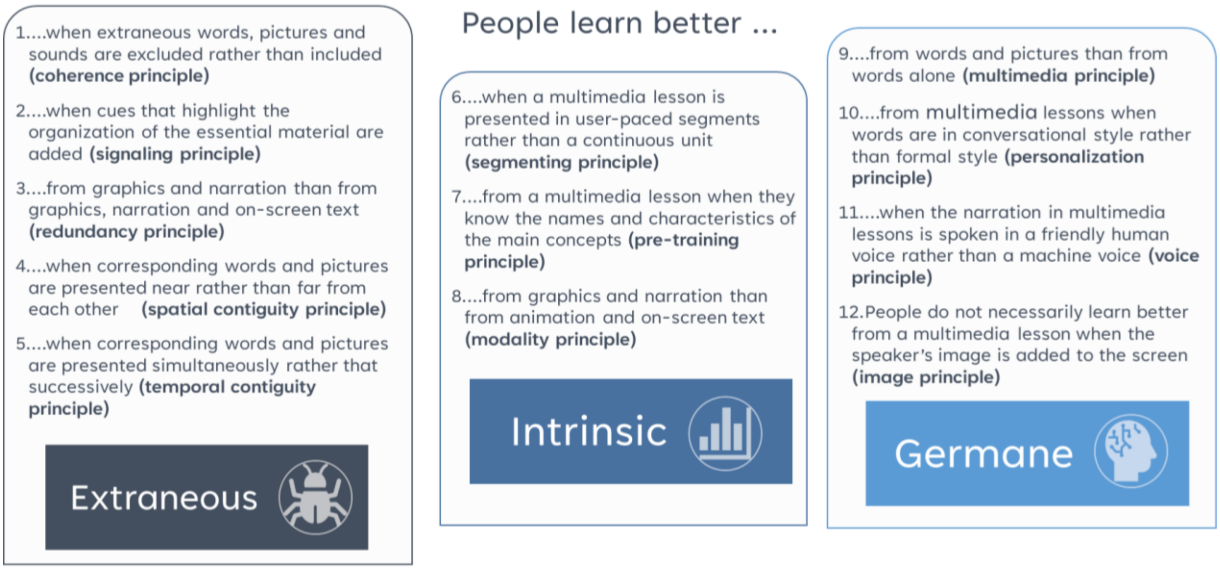

Figure 1. Twelve principles of multimedia learning (based on Mayer (2009))

2.2.2. The script theory of guidance in CSCL

Computer-supported collaborative learning (CSCL) theory focuses on computer mediated communication between humans (and computers) whilst promoting the ideas of Piaget and Vygotsky socio-cultural theories about learning via social interaction. Collaboration can be described as a "process of participating in knowledge communities" (Lipponen, 2002). Collaborators work on some shared problem, trying to conceptualize it together and develop collective understanding. This process of working together leads to co-construction and distribution of knowledge from one learner to another. Interactive video can provide several ways of collaborative tasks for peer-learning, such as doing quizzes together or creating new interactive videos in a class setup (Cattaneo et al., 2018).

Although online collaborative tasks are praised for training essential soft skills, learners often perceive them as frustrating experiences (Capdeferro & Romero, 2012). Teachers intending to use interactive video for online group learning activities must be aware of the commonly experienced risks associated with CSCL, such as student resistance to team-work (Roberts & McInnerney, 2007). One of strategies that can promote collaboration is creating positive interdependence in a group of learners (Laal, 2013). For example, positive resource interdependence is created when information is distributed unevenly between the group members. It is similar to a hidden profile paradigm task, in which some of information is shared in group and some is individual (Stasser & Titus, 1985). The group members need to share their individual information to solve such a collaborative task. Information sharing is central for efficient communication online, it can be enacted with the help of video annotations, chat, web-camera, microphone etc.

Appropriate instructions and grounded external assistance would help learners achieve the learning goals and reduce possible anxiety from collaboration online. The script theory of guidance in CSCL describes learner activity in terms of internal and external collaboration script principles (Fischer, Kollar, Stegmann, & Wecker, 2013).

Internal collaboration script is what group members would do by themselves naturally, which in turn is based on their knowledge about collaborative practices. This knowledge can be ranked in four hierarchical levels (Figure 2): *play, scene, scriplet,* and *role*, in analogy with a theatrical play. Internal script can be based on learner's previous experiences or induced, for example, through observation of a model collaboration.

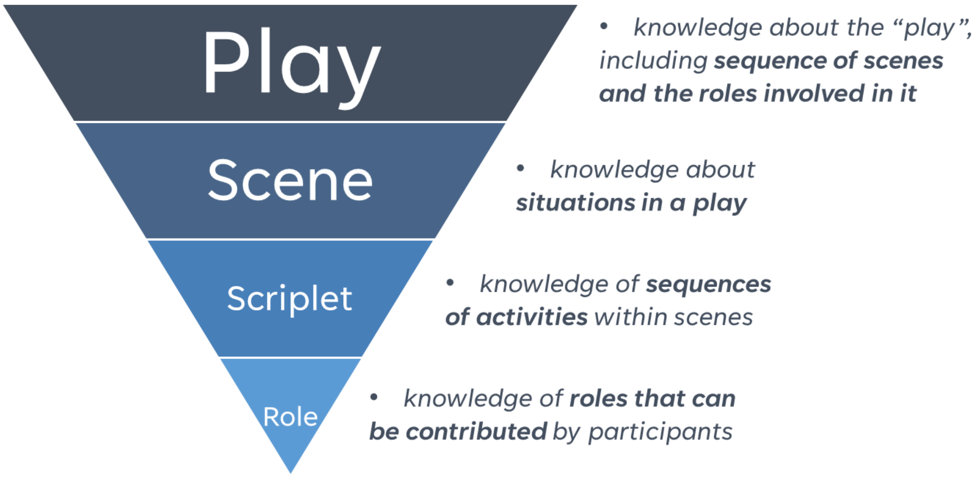

Figure 2. Components of knowledge about a collaborative practice according to the script theory of guidance (based on Fischer et al. (2013))

External collaboration script are instructions for the task provided by an external source (e.g., learning interface or teacher) that help actors orient better in the play. The external script components act as scaffolds for knowledge acquisition at a higher-level: play scaffolds provide general task definitions and collaboration goals, scene scaffolds put task activities in a sequence, role scaffolds assign roles to the participants and scriplet scaffolds prompt learners to apply their available scriplets in a scene. Task scaffolding also helps reduce the cognitive load on individual learners. On the other hand, overscripting, i.e., redundant instructions on inappropriate level may as well destroy naturally occurring collaboration, put unnecessary load on a learner and inhibit knowledge acquisition. Taking regulation away from the learners might block their self-regulated evolution of higher-level internal script components. The aim is to configure external script so that it optimally promotes internal script (Fischer et al., 2013).

In interactive video, external collaboration script can be balanced for example, through the number of exchange interactions appearing on the screen. According to the optimal external scripting level principle, "An external collaboration script is most effective for knowledge acquisition if it is directed at the highest possible hierarchical level of internal collaboration script components for which subordinate components are already available to the learner" (Fischer et al., 2013). That means stating aim at the beginning of video experiment (play) and describing the experiment stages (scenes) would be more essential than giving annotations for each action to be performed (scriplet, role).

2.2.3. The concept of flow in positive psychology

A concept of flow could be used to describe optimal experience with a task. Being *in flow* is a subjective engagement in some activity that provides feasible challenges, transparent goals and instant feedback. Then a person does not waste energy on worrying about succeeding the task and just enjoys the activity, which becomes a rewarding experience itself. Further flow experience attributes are that a person stays focused and has a sense control over the activity; meanwhile, time spent on the task seem to be passing very quickly. The flow construct is universal: same characteristics have been observed regardless cultural, gender or age differences. It has been applied in many spheres, such as sports, work, learning and entertainment (Csikszentmihalyi, 2014). Interesting and engaging tasks are more likely to raise intrinsic motivation to learn. Therefore, flow is similarly important as acquisition of conceptual knowledge.

The flow can be modelled as a balance between perceived opportunities for action (challenges) and capabilities (skills). A simple flow model (Figure 3) shows that flow occurs when the challenge matches the skill. From a more advanced view, flow requires both challenge and skill to be reasonably high – the task should be just-manageable (Csikszentmihalyi, 2014).

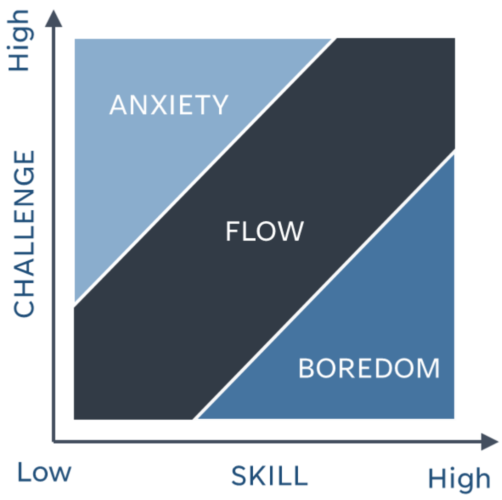

Figure 3. Simple flow model (adapted from Csikszentmihalyi (2014))

Is it possible to achieve flow through design of interactive video? The three key features that promote flow are (1) clear goals, (2) balanced challenge and skills, and (3) clear and immediate feedback (Csikszentmihalyi, 2014). Interactive video has all the needed features for defining goals and providing feedback (annotations, hyperlinks, quizzes), and the balance of challenge and skills may be achieved, for example, by choosing an individual learning trajectory.

To sum up on the theoretical framework, cognitive theories propose how to manage cognitive load and learning, socio-cultural – how to manage collaboration and interaction in the learning tasks, positive psychology – how to manage the flow and enjoy learning. All of these may have implications in online learning and have to be considered for the design of educational video.

2.3. Research question and hypotheses

The aim of this study is to investigate possible influence of interactive features on student perceptions of learning with video. The research question is: How do different interactivity features of an online video experiment in physics influence student collaboration and flow?

Figure 4 shows a schematic of the quantitative research that will be conducted to find an answer to the research question. The independent variable is interactivity, and the dependent variables are collaboration and flow. The level of interactivity varies from low (None) to high (Advanced) by adding different interactive H5P features to a video experiment. The following hypotheses will be tested:

- H_1 Interactive H5P video experiment would increase flow compared to raw video.
- H_2 Interactive H5P video experiment with a hidden profile task would increase collaboration compared to simple interactive or raw video.

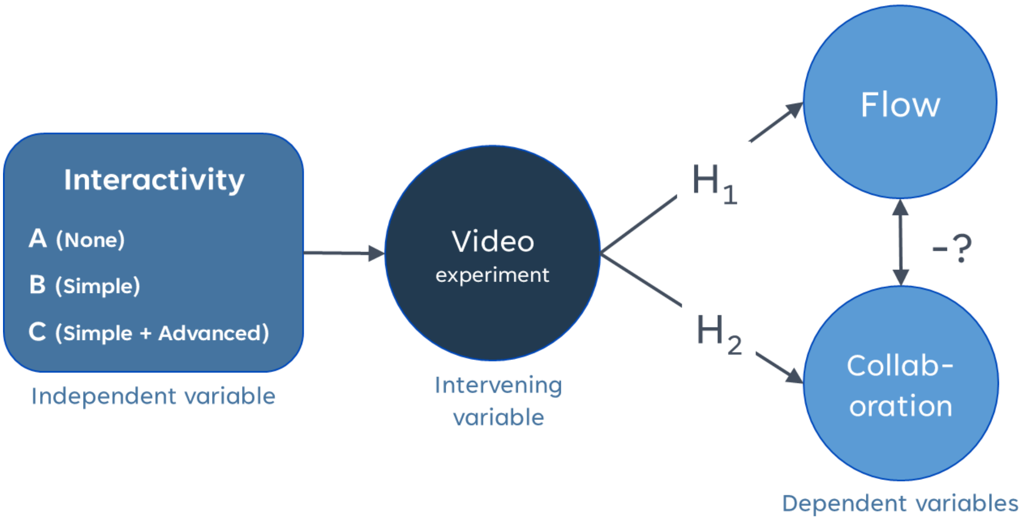

Figure 4. A schematic of quantitative research studying how interactivity level influence collaboration and flow in online video experimentation.

In addition, there might be interdependence between the collaboration and flow. It is expected to be negative and should be considered in interpretation of the results. Qualitative observations will help put the quantitative results into perspective.

3. Method

The research described in this work together with preparation was conducted during two semesters of the academic year 2021/22. The preparation started in September 2021 with reviewing literature, learning how to design and implement interactive video in the study process, how to perform various research methods, how to collect and analyze data. Several short interactive videos were tested with groups of students, and discussions with teachers were initiated. Feedback from students and teachers involved in the study process helped understand attitudes towards video as a study material, possible applications and types of interactive content preferred by users. The preparation had been fulfilled by February 2022 with a first video experiment prototype "Elasticity"[3], which was designed and implemented in the study process. Feedback from students and teachers about the prototype experiment was used to assess the optimal amount of interactive content and possible technical improvements. Results of the preliminary research were discussed at two conferences (see Appendix 1). The preparation helped better formulate the research question and the hypotheses.

Finally, when the research question and hypotheses had been stated, the video experiment intervention took place in March 2022. Three variations (A, B, C) of a new video experiment "Viscosity"[4] were implemented with a sample of students, data was collected by observations and a survey to address the research question. The intervention, research design, sample, instruments, data collection and analysis for this final part are described in the following sub-chapters.

3.1. Three variations of the video experiment "Viscosity"

The video experiment was created following the phases of the model for designing hypervideo-based instructional scenarios (Cattaneo et al., 2019). In the preparation phase, the experiment video was recorded with digital cameras (*Canon, Fujifilm, iPhone, Huawei*) and processed on computer-based video-editing software (*DaVinci Resolve, Photos*). In the production phase, the raw video was posted on *YouTube*, and interactive content was added to it using a H5P plugin in *Moodle*. Finally, the interactive video was published (*Moodle, h5p.org)* and direct links were added to *Moodle* for the use by the university students.

[3] A link to the interactive version of the video experiment "Elasticity": https://h5p.org/node/1248455

[4] Links to the three variations of the experiment "Viscosity": A - raw video https://youtu.be/nLheom6EsQ4; B - simple interactive video https://h5p.org/node/1256101; C - branching scenario video https://h5p.org/node/1256747

Viscosity was the topic of the class in Medical Physics, and the aim of the practical work was to determine the viscosity of glycerin with two methods. The video experiment could be thematically split into two parts:

- Part I (~4 min) described experimental setup of a rotational viscometer (*ICA Rotavisc*) with a temperature probe and showed the procedure of viscosity-temperature measurements. Approximately 15 measurements could be taken for the glycerin cooling process from 40°C to 20°C.
- Part II (~15 min) showed the Stokes' falling sphere method, in which the viscosity is determined from the velocities of small solid spheres falling in liquid glycerin. It showed the experiment schematics and theoretical formulae, then the procedure to read the sphere size from a microscope scale, and finally, measurements. The measurements of the sphere size, falling times and temperature could be taken for 6 samples.

The video experiment was designed considering the multimedia principles and the principles for the flow, described in the theoretical framework. Adding H5P enabled three variations of the video experiment (A, B, C) with different levels of interactivity (Table 1).

Table 1. Characteristics of the video experiment with different levels of interactivity.

	A	*B*	*C*
Video format	Raw video	Simple interactive	Branching scenario
Interactive features (control, hyperlinks, exchange)	✗	✓	✓
Branching scenario (hidden profile task)	✗	✗	✓

A. The raw video version had no additional interactive features.

B. The simple interactive version had hyperlinks, such as descriptions about the experimental setup (Figure 5), control features, such as navigation menu (Figure 6), and exchange options, such as direct instructions and self-check quiz questions (Figure 7a-c).

C. The branching scenario version had an additional branching feature. The raw video was split into separate clips that were arranged into a branching tree (Figure 8). The hidden profile task was incorporated in the Stoke's method part by introducing roles for Student A and Student B. The viewer (Student A or B) could see either the sphere size or the falling times for any of the 6 samples. Each clip contained same interactive features as in the simple interactive version.

Figure 5. Interactive descriptions of the experimental setup added as hyperlinks next to the objects. Clicking on a label would open a text window with a short description of the object or process. For example, clicking on "Falling sphere" (next to the dark dot) would open a description: "A small sphere made of steel is let to fall in a viscous liquid".

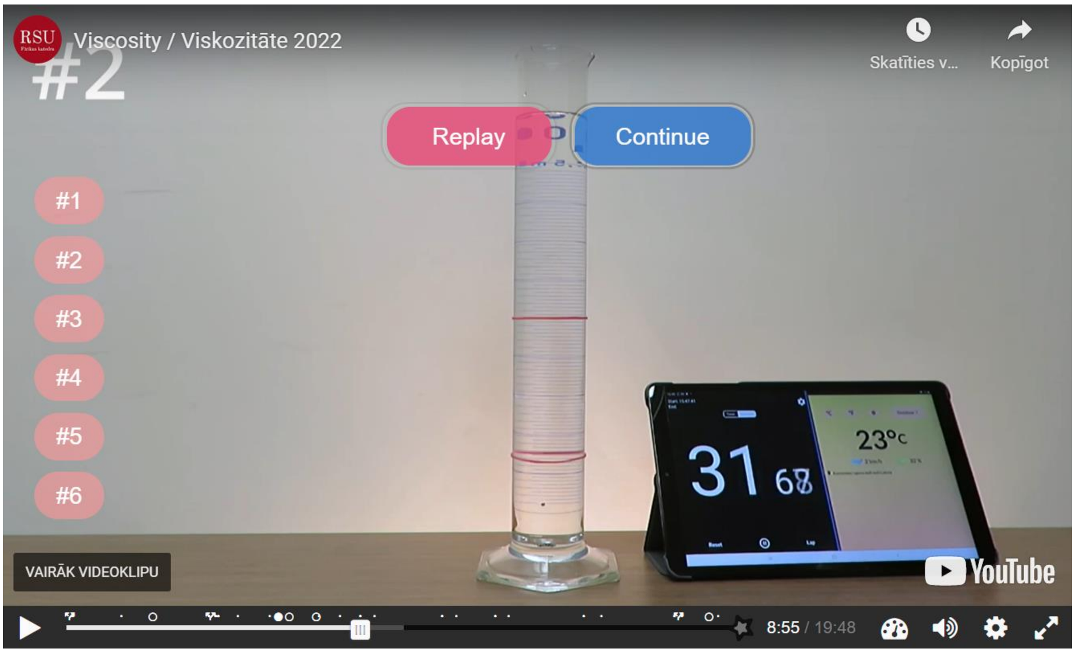

Figure 6. Interactive control features linked to the timeline. Clicking on the left panel allows the viewer to select one of 6 samples for measurements. Clicking on "Replay" or "Continue" would navigate the viewer back or forth on the timeline.

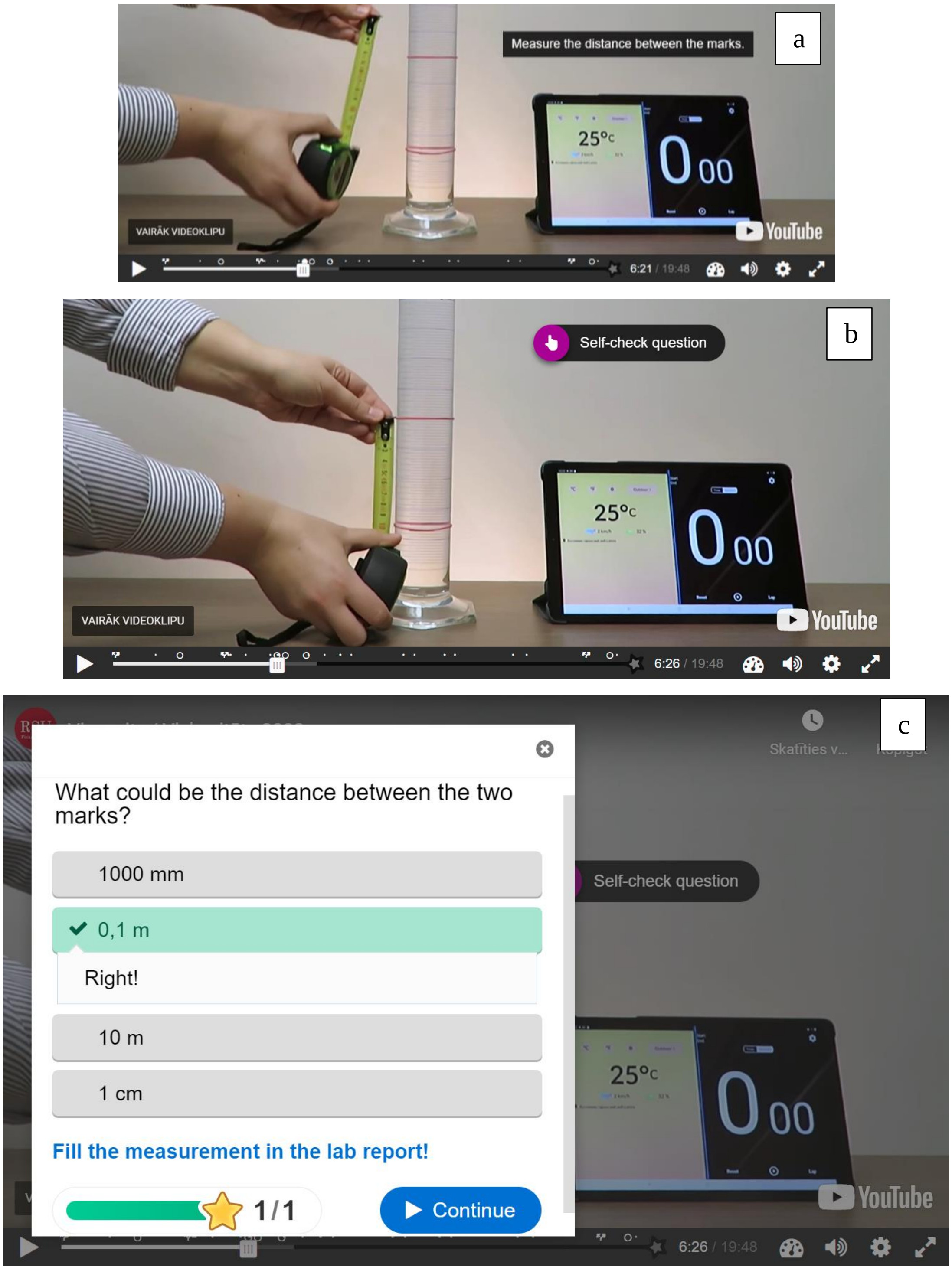

Figure 7. Interactive content consequently appearing on the screen during the play: annotation with instructions (a), a thumbnail to a self-check-question after the action (b), and automated feedback after answering the question (c).

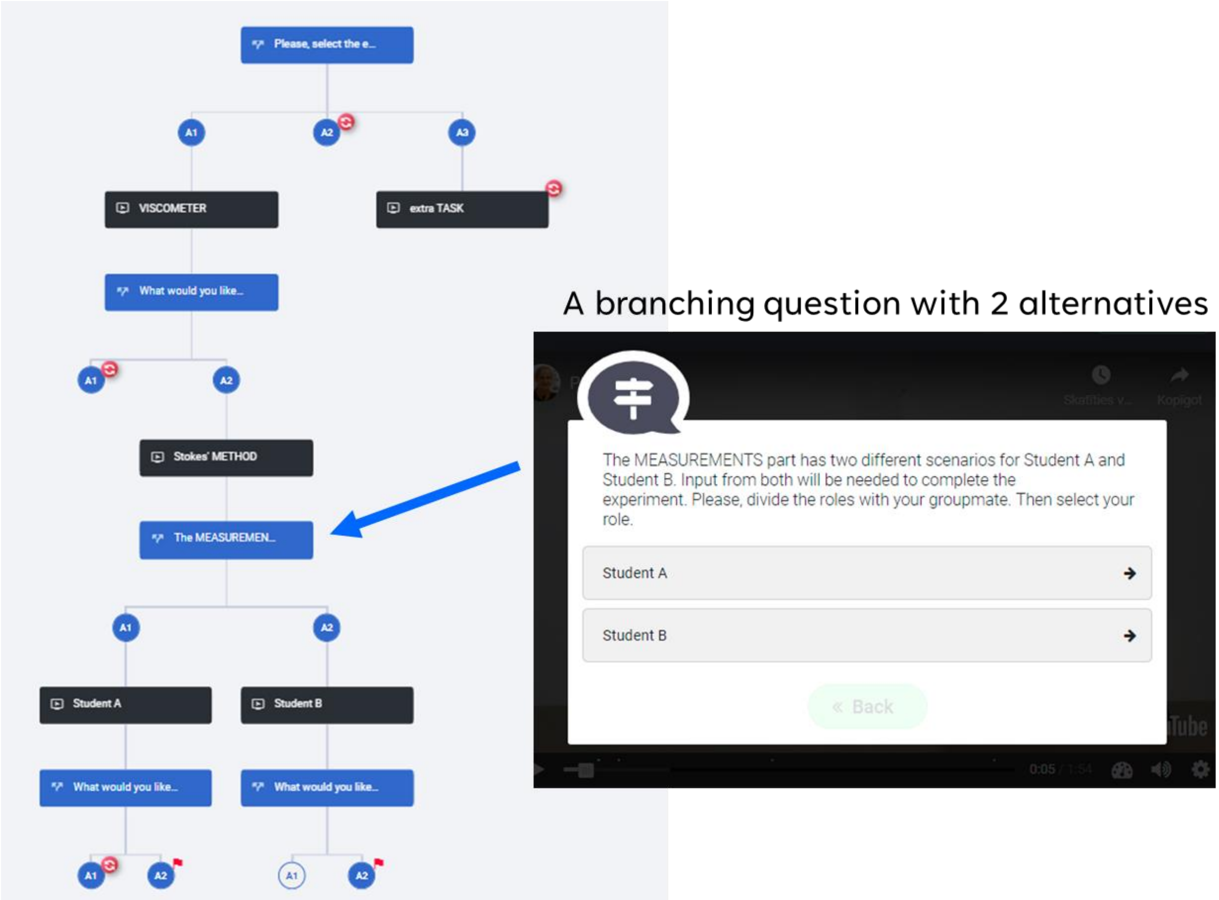

Figure 8. The branching scenario with an example of a branching question.

The three variations of the video experiment had different external script levels (Table 2). Each video had frames with text for the title (play), and parts of the experiment (scene). Noticeably, the raw video did not contain script on the scriplet or role level, but interactive did. In the study course of Medical Physics at the host university where the study was conducted, students typically work with lab report templates containing instructions for the measurements and analysis, which they use in parallel with watching video experiment. Such a template was prepared in *Excel* file format (Appendix 2). The instructions from the lab report were incorporated in the interactive versions (B, C), consequently changing the external script level from scene (e.g., denoting a phase of the experiment) to role (e.g., direct instructions for action). In addition to instructions for measurements (B). In addition, branching scenario (C) contained script instructions for collaboration with the partner.

Like previous online experiments in the course, the video experiment "Viscosity" was without audio narration. Talking or music might interfere with student discussions during the watching. The sound segmenting measurements.

Table 2. Variations of the external script level in three versions of the video experiment

	A	*B*	*C*
Play	✓	✓	✓
Scene	✓	✓	✓
Scriplet	✗	✓	✓
Role	✗	✓	✓

Prior to the final intervention with study participants (students), the video experiments were reviewed by one experienced filmmaker and two Doctors of Physics, revised and tested by four volunteers (two study process managers, two teaching physicists). This allowed an estimation of the time needed to complete the experiment and revealed potential issues with instructions. For example, the branching scenario version was revised. Initial instruction appearing at the branching question was: “The MEASUREMENTS part has two different scenarios for Student A and Student B. You will need to collaborate to collect all the needed measurements! Please, divide the roles with your groupmate. Then select your role”. However, the trial participants misinterpreted the task goal and failed to share individual measurements. For the final version, the instructions about the collaborative task with a hidden profile were made more explicit: the branching question was modified (Figure 8) and additional detailed instructions added (Figure 9).

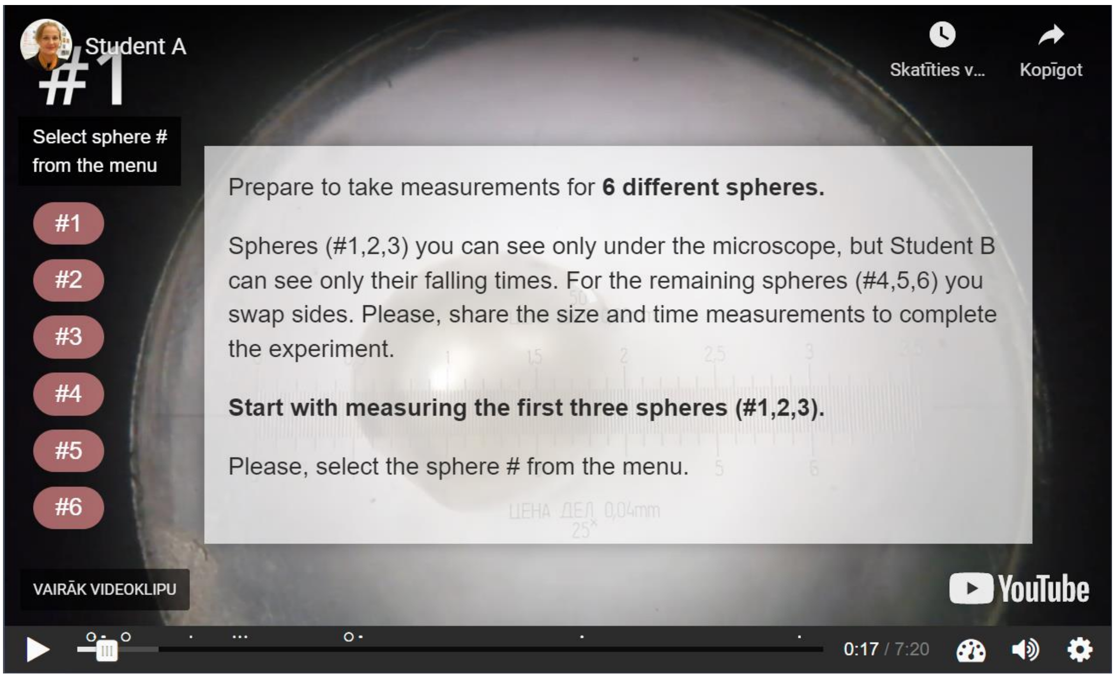

Figure 9. An example of instructions for the selected role (Student A) in the branching scenario video experiment.

3.2. Mixed quasi-experimental research design

The mixed method quasi-experimental research design was used. Data was collected by observations and surveys; qualitative data aimed to support the main findings from the quantitative surveys. The research participants were assigned in three experimental groups (A, B, C) for a video experiment intervention with varying level of interactivity (simple interactions – X, branching scenario – Y), measured and observed (O):

Group A		O
Group B	X	O
Group C	XY	O

3.3. Sample of undergraduate students

Convenience sampling was applied to select a sample of 72 students (51 female, 21 male) from international medical students enrolled in the 1st study semester at Riga Stradins University. The sample students belonged to 6 study groups (from 8 to 14 students per group), which had been assigned to the researcher for teaching the Medical Physics course during Spring 2022 semester. The participants were informed in oral form about the research at the beginning of the semester, as well as before the intervention and in written form before filling the survey (informed consent). At the time of intervention, 68 students participated in the online class and did the video experiment, 65 answered the post-questionnaire (96% response rate).

3.4. Survey instrument for measuring collaboration and flow

A self-report questionnaire was the main instrument to measure student collaboration and flow during the video experiment (see Appendix 3). The questionnaire had 24 items grouped in 5 sections: Challenge and skills, Flow, Ease of use, Collaboration, Additional information. The items were adapted from different publications, where they had been validated previously.

1. The items in Challenge and skills were adapted from the paper "The ebb and flow in online learning" (Pearce, Ainley, & Howard, 2005). Originally, they were used to monitor the flow path during an online physics class with a number of short tasks. The questions should address a specific task, so they were formulated to ask specifically about the second part of the video experiment (Stokes' method).

2. The items in Flow were also adapted from the paper “The ebb and flow in online learning” (Pearce et al., 2005). Originally, they were used to measure student control, engagement and enjoyment in the online class.
3. The Ease of use questions were adapted from “Flow in computer-mediated communication: Electronic mail and voice mail evaluation and impacts” (Trevino & Webster, 1992).
4. The Collaboration items are adapted from “The laboratory course assessment survey: a tool to measure three dimensions of research-course design” (Corwin, Runyon, Robinson, & Dolan, 2015). Originally, they were a part of questionnaire about a course, so their Likert-scale ratings were designed to reflect the frequency of collaboration (Never, One or two times, Monthly, Weekly, I don’t know, I prefer not to respond). The scale was adapted to reflect attitudes (Strongly disagree, Disagree, Neutral, Agree, Strongly agree), because of the much shorter time period for intervention assessed in this study (25 minutes).
5. The Additional information items were aimed to compare how the respondents interacted and explain possible differences in their experiences:

5.1 Which options did you use for communication with your groupmate?
Please, select all that was used during the video-experiment.

- ☐ Chat
- ☐ Microphone
- ☐ Web-camera
- ☐ Screen sharing
- ☐ Other

5.2. A place for additional comments and feedback in free form.

The sections 1-4 had 5-point Likert-scale items. The section 5 with feedback in free form would collect qualitative data. The questionnaire form began with the *informed consent*, which described the research purpose, stated voluntary and anonymous participation, and provided the contact email address.

Prior to the final measurements with the study participants (students), the survey instrument items had been reviewed and tested with four volunteers (two study process managers, two teaching physicists). After the tests some of the instructions were paraphrased, for example, instructions for the collaboration parts allowed for not answering in case the experiment was performed individually. The use of the questionnaire for the research means was approved by the Research Ethics Committee at Riga Stradins University (document number 2-PĒK-4/239/2022).

3.5. Data collection and analysis

The intervention and data collection from six study groups took place for two days, within six 90-minute regular online classes in *Zoom (*Figure 10*)*. The class would begin as usual with a theoretical presentation (*MS PowerPoint*) about the topic of the video experiment (~50 min). Then students would be randomly allocated in *Zoom* breakout rooms for 25 minutes (2 people per room, 3 in the case of odd number of students) to perform the video experiment. For the observations, researcher joined some of the breakout rooms for 1-2 minutes during the experiment session, asked students about the work progress, took notes. Students were asked to complete the voluntary and anonymous questionnaire to reflect on their experience with the video experiment immediately after the breakout room session. The electronic survey questionnaire was prepared in *MS Forms*, distributed via a hyperlink, and took participants in average 3 minutes to complete.

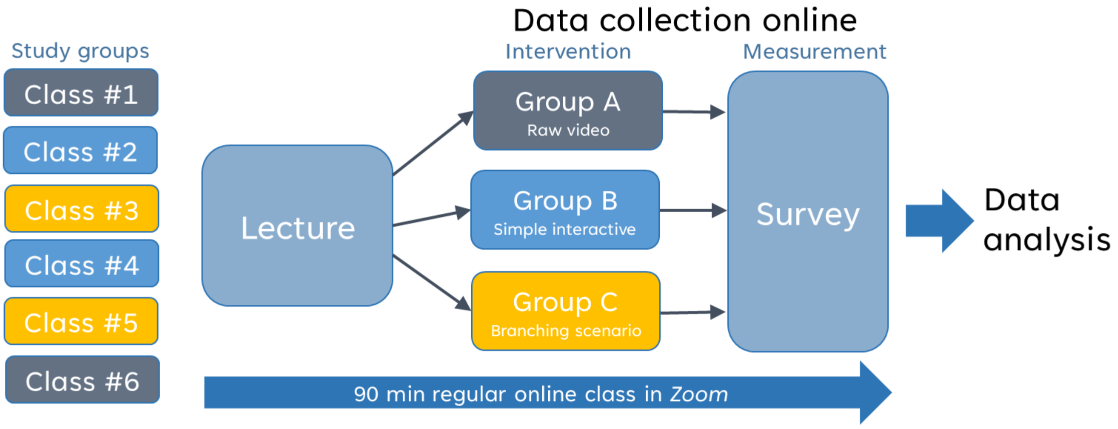

Figure 10. Organization of the data collection and analysis

Analysis of the collected quantitative data was conducted in *MS Excel*. The Likert scale responses were converted into values from 1 to 5. Each part of the questionnaire (e.g., Collaboration, Flow) was analyzed independently from others, incomplete responses to one part were excluded from the analysis of that part. The Flow items were subjects to reverse scoring. Three participants that responded to all Flow items similarly were excluded from the analysis.

Statistical analysis included calculating the central tendency parameters (mean, mode, median, standard deviation), conducting statistics tests (Mann-Whitney U test, Pearson's test). The significance level was set to 0.05 in all tests. In addition to *MS Excel*, some tests were conducted using an online calculator.[5]

[5] Mann-Whitney U test online calculator https://www.socscistatistics.com/tests/mannwhitney/default2.aspx

4. Results

In this chapter the main findings, collected as set out in Chapter 3, will be outlined and presented. Quantitative results of the flow and collaboration measurements are followed by qualitative observations and analysis of the free-form responses from students.

4.1. Flow and skill-challenge balance

The main findings for the flow measurements are presented Table 3. Responses from individual participants that answered all 11 Flow questions were included in the calculation of means and standard deviations (Stdev).[6] Considering the mean scores above 3, all three groups experienced flow. The scores in the interactive video experiments (B, C) are higher than in the raw video (A).

Table 3. Means and standard deviations from the responses to Flow.

Group	Intervention	Mean*	Stdev
Group A (n = 24)	Raw video	3.30	0.44
Group B (n = 21)	Simple interactive	3.64	0.55
Group C (n = 16)	Branching scenario	3.62	0.45

*The group mean scores were calculated from the mean scores of individual participants for the 11 Flow items, using the Likert scale conversion (Strongly disagree = 1, Disagree = 2, Neutral = 3, Agree = 4, Strongly agree = 5).

Two-tailed Mann-Whitney U tests were conducted to compare the groups and test the hypothesis H_1: Interactive H5P video experiment would increase flow compared to raw video**.** They showed significant difference between Group A and Group B (z-score -2.30, p-value 0.021), as well as between Group A and Group C (z-score -1.97, p-value 0.049). The results are significant at p-value < 0.05.

Next, responses on specific Flow items were analyzed. The mode values are compared in Figure 11. The item #11 “It required a lot of effort for me to concentrate on the video-experiment.” had most diverse responses. For Group A the mode was Agree (42% responses), whilst for Group B – Disagree (43%) and for Group C – Neutral (44%). Two-tailed Mann-Whitney U test revealed significant difference between Group A and Group B (z-score 2.73, p-value 0.006).

[6] All but one participant (Group C) completed the Flow part of the survey. Incomplete response was excluded from the assessment of flow.

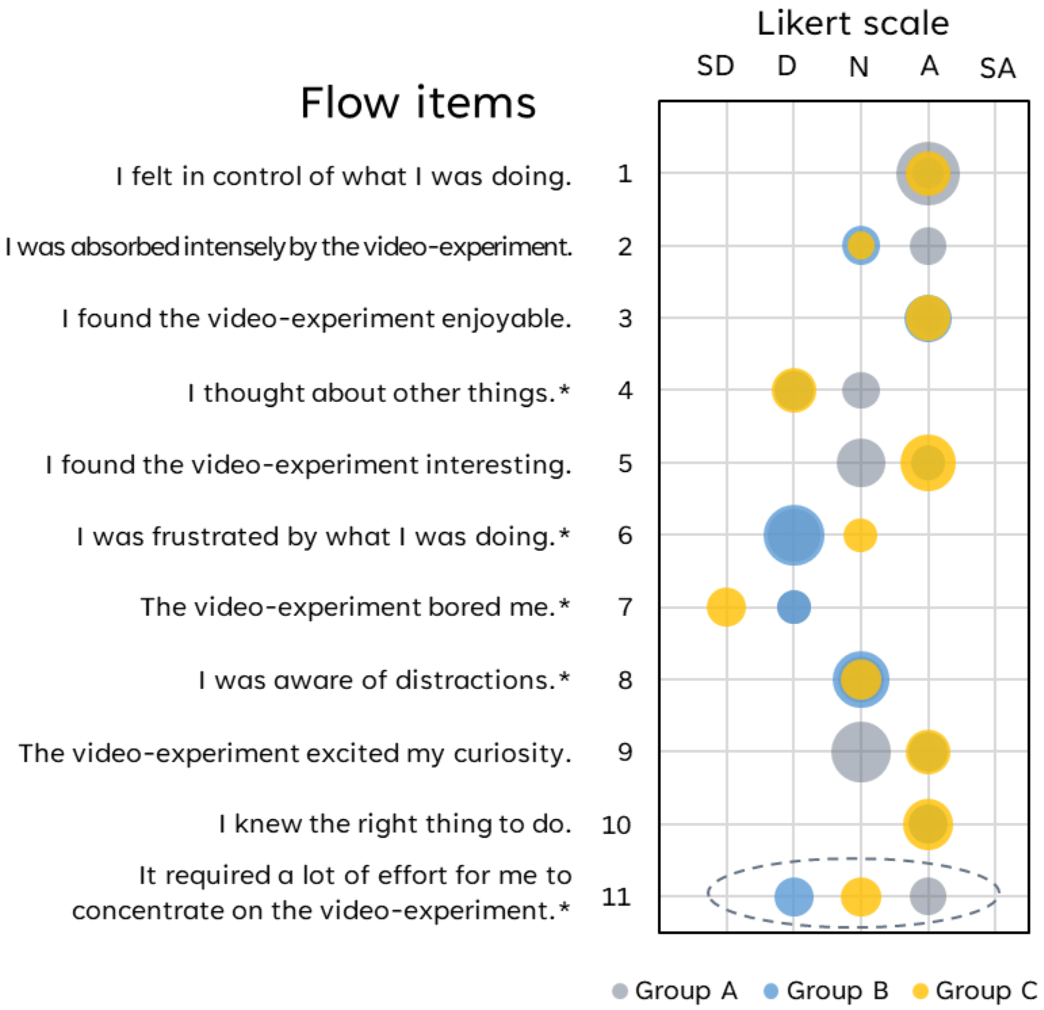

Figure 11. Mode responses to the Flow items on the Likert scale: SD – Strongly disagree, D – Disagree, N – Neutral, A – Agree, SA – Strongly agree. The bubble size shows proportion of mode responses relative to the group size. Likert scale points for item #11 are circled with a dashed line for emphasis. Reverse scoring items are marked with *.

The flow was further assessed by analyzing the perceived challenge and skill, which is an alternative way of measuring the flow as a dynamic process (Pearce et al., 2005). The results from the challenge and skills measurements for the last part of the video experiment (Stokes' method) are presented in Figure 12. In each group, about half (48-62%) of the participants reported matching of challenge and skills. Yet, some difference can be observed from the distribution of the datapoints around the theoretical path (challenge = skill). In the simple flow model, the region above the challenge = skill path corresponds to anxiety, and below the path is boredom. In Groups B, no responses corresponded to boredom and more pronounced tendency to anxiety than in Group A or Group C could be seen.

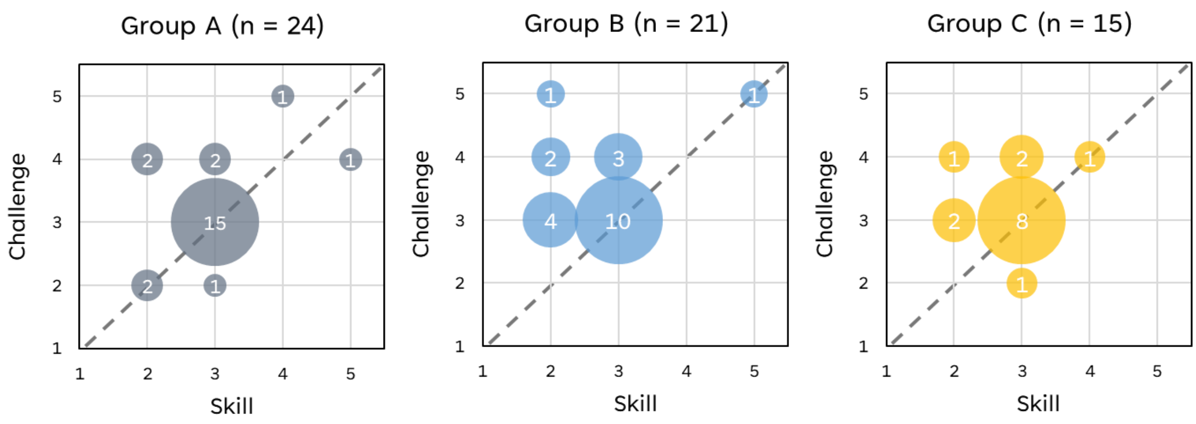

Figure 12. The flow measurements on the challenge-skill coordinates (Too low = 1, Just right = 3, Too high =5). Bubble size represents the proportion of responses at each coordinate. The dashed line is a reference for the flow theoretical path (challenge = skill).

The challenge-skill balance is fragile and may change several times even during one lesson. Therefore, it should be measured as close to the moment of activity as possible and one must distinguish task-flow and artefact flow (Finneran & Zhang, 2002; Pearce et al., 2005). The two challenge-skill questions asked about the last part of the video experiment and appeared in the post-survey first, so the measurement was done as close to the moment of activity as possible. To ensure that the flow was not significantly affected by H5P technology itself (possible artefact-flow), three items measuring Ease of use were included in the post-questionnaire. The calculated mean scores are similar for all three groups: Mean (Stdev) was 3.62 (0.65) in Group A, 3.95 (0.77) in Group B, and 3.71 (0.71) in Group C. High scores > 3 suggest students acknowledged the technology of video experiment (raw video or H5P) and found it easy to use.

4.2. Collaboration and communication

Table 4 summarizes the main findings for the measurements of collaboration perception by the self-report survey. The group mean scores were calculated from the mean scores of individual participants that answered all 6 collaboration questions.[7] Compared to Group A (raw video), perceived collaboration was lower for Group B working with the simple interactive video, but it increased in Group C (branching scenario).

[7] Five participants in Group A, one participant in Group B and one in Group C did not fully complete the Collaboration part of the survey. Incomplete responses were excluded from the assessment of collaboration.

Table 4. Means and standard deviations from the responses to Collaboration

Group	Intervention	Mean*	Stdev
Group A (n = 19)	Raw video	3.64	0.50
Group B (n = 20)	Simple interactive	3.18	0.31
Group C (n = 16)	Branching scenario	3.88	0.49

*The group mean scores were calculated from the mean scores of individual participants for the 6 collaboration items, using the Likert scale conversion (Strongly disagree = 1, Disagree = 2, Neutral = 3, Agree = 4, Strongly agree = 5).

Two-tailed Mann-Whitney U tests were conducted to compare the groups and test the hypothesis: H_2 Interactive H5P video experiment with a hidden profile task would increase collaboration compared to simple interactive or raw video experiment. Collaboration in Group B that performed simple interactive video was significantly different from Group A (z-score -2.99, p-value 0.003) or Group C (z-score -3.85, p-value < 0.001). The difference between Group A and Group C was not statistically significant (z-score -1.52, p-value 0.129).

In addition, possible differences on specific Collaboration items were analyzed. The mode values for each of the 6 items are compared in Figure 13. The responses for Group B are consistently shifted to Neutral, compared to Group A and Group C that most frequently chose Agree in each of the items. As follows, all statements about collaboration show similar tendency.

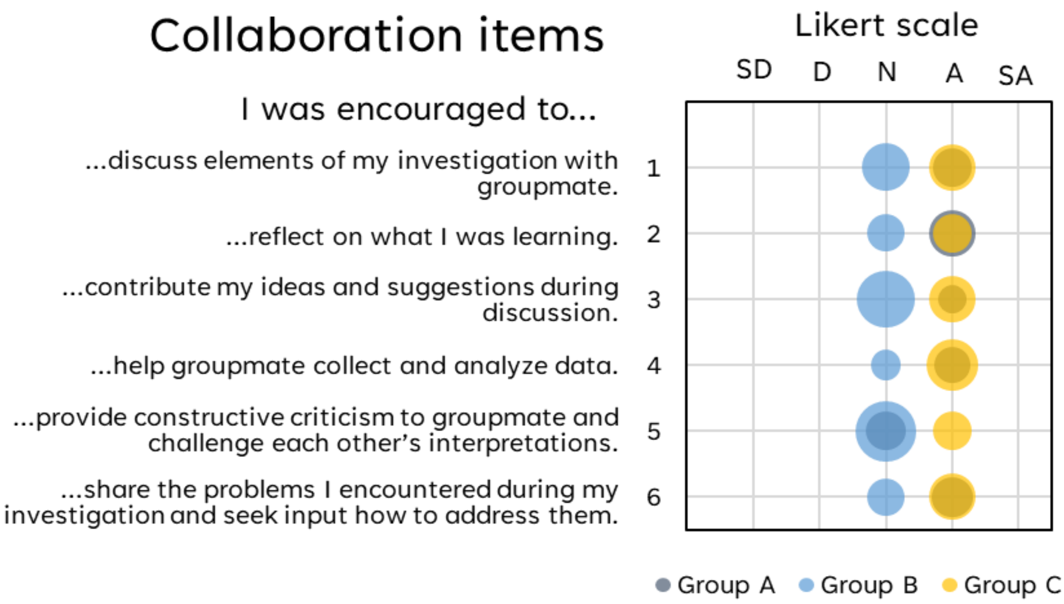

Figure 13. Mode responses to the Collaboration items on the Likert scale: SD – Strongly disagree, D – Disagree, N – Neutral, A – Agree, SA – Strongly agree. The size of the bubbles represents proportion of mode responses relative to the group size.

There is further evidence that collaboration in the branching scenario video was higher than in the raw video. Although the Mann-Whitney test did not provide enough evidence for a significant difference between Group A and Group C, it should be noted that some participants did not complete the Collaboration part, possibly because they performed the experiment with minimal communication. Five (21%) students in Group A, and only one in Group B (5%) as well as C (6%) did not complete Collaboration. There was an additional question in the survey: "Which options did you use for communication with your groupmate?", and it also remained unanswered by those skipping the Collaboration part. Microphone and web-camera were used by more than 80% respondents in each group. Other options, such as screen-sharing or chat, were somewhat less popular and used by less than half of the respondents. However, the screen-sharing was more frequently reported in Group C (56%) compared to Group A or B (33%), which suggests a higher level of information exchange for the hidden profile task. Considering five blank responses in Group A would affect the results and also leverage the collaboration level towards Group C.

Finally, Pearson's correlation coefficient was computed to assess the linear relationship between the perceived collaboration and flow in each group.[8] There was weak positive correlation in all three groups: in Group A, $r(17) = 0.22$, p-value 0.372; in Group B, $r(18) = 0.29$, p-value 0.214, and in Group C $r(13) = 0.36$, p-value 0.179. The result is not statistically significant.

4.3. Qualitative observations and student feedback

The following analysis shall provide further arguments to the aspects of collaboration and flow between the three groups, based on observations and student free form responses (Appendix 4).

Group A (raw video) marks a baseline for student collaboration and flow in a typical video experiment in the course. Watching video experiment and reading the instructions from a lab report was a typical approach during the semester, hence students could recreate the script for collaboration based on their previous experiences. From observations during the intervention, students watched the experiment individually or using a shared screen, discussed the video together to obtain mutual understanding of the task, similarly to previous practical works online.

[8] Only the responses from participants that completed both Collaboration and Flow parts were included in calculation: 19 in Group A, 21 in Group B and 17 in Group C.

Group B (simple interactive video) showed higher flow but lower collaboration, compared to Group A, which could be explained with additional interactive H5P features. The amount of external script in the video increased because the instructions from the lab report appeared on the screen as annotations (see e.g., Figure 7a). On one hand, it was supposed to reduce the extraneous cognitive load on the learner by fulfilling the spatial and temporal contiguity multimedia principles (Figure 1). However, it also might inhibit naturally occurring collaboration. Interactive exchange options in the video (e.g., quiz in Figure 7b,c) reduced the need in human interaction, as each student could check their understanding and progress individually. In two *Zoom* breakout rooms checked during the intervention, students seemed to be working individually rather than actively discussing the experiment, they had no questions.

Group C (branching scenario) maintained both collaboration and flow at a relatively high level. Increased collaboration compared to simple interactive video could be primarily attributed to the hidden profile task, which in turn was created by adding advanced interactive features (branching scenario) to the video. To support collaboration, the amount of external script was increased to contain specific role instructions. Presumably, branching scenario H5P could be a new experience for students since this was the first of such a video in the course. Novelty could trigger collaboration – students tried to understand the task together. At the same time, the new design of video might be challenging; for example, one small group (3 students) that were visited at the end of the 25-minute-long intervention still struggled to begin the Part II of the video experiment. This was reflected in one written response: “My group did not know there were two parts to the second video, some clarification would be helpful :)”.

Student feedback provided an insight to their preferences for online experimentation. Although students were used to work with video and supporting files, they would wish the instructions to be incorporated in the video. This was reflected in feedback from Group A: “I would like to have the instructions maybe written out in the experiment or circled what is important for doing the tasks at hand”. Meanwhile, the interactive video users pointed out the need for more time to complete the task: “…there was no time left to discuss after taking measurements” (Group B), “Could use a bit more time in the breakout rooms.” (Group C). Such responses indicate demand for managing cognitive load in online experimentation.

Technical video quality turns out to be of a high importance to online experimentations, regardless of the interactivity. Students compared the video experiment to the previous one: “The video quality was better than that of the other interactive video experiment we did before!” and pointed out drawbacks: “very hard to see the balls in the liquid”. Insufficient resolution of video has been a central theme of their previous feedback for the pilot experiment “Elasticity”.

5. Discussion

The aim of this study was to investigate possible influence of interactive video features on student collaboration and flow during online experimentation in physics. Significant differences between the three video experiments with varying interactivity level were revealed from quantitative results and supported by observations in mixed-method research.

5.1. H_1 Interactive H5P video experiment would increase flow compared to raw video

The results support the hypothesis H_1 about the flow increase in the interactive video experiment. Flow scores were significantly higher for both interactive videos compared to the raw video. As stated in the theoretical framework, the three key features that promote flow are clear goals, balanced challenge and skills, and clear and immediate feedback (Csikszentmihalyi, 2014). The goals and the challenge-skill balances were approximately similar in all three videos; therefore, immediate feedback from H5P quizzes embedded in the video timeline is what appears to make the difference. Embedding interactive questions in video has been recommended as a successful strategy for active learning, as it may increase germane load and improve student self-assessment (Brame, 2016).

Analysis of separate Flow items revealed that interactive features significantly improved the aspect of attention, which also outlines the good effect of interactivity on cognitive processes. Following recommendations for effective educational videos (Brame, 2016), chunking video in shorter segments balances intrinsic cognitive load. The raw video experiment in the present study was initially 19 minute long, interactive H5P features (forced stops, index) split it into several meaningful 2-4-minute segments. A large empirical study on online educational videos has demonstrated that student engagement is highest for short videos and proposed to segment educational videos into chunks shorter than 6 minutes (Guo, Kim, & Rubin, 2014). Another study, which compared different length interactive educational videos (Afify, 2020) found that interactive video shorter than 6 minutes outperform long ones in terms of student cognitive achievement and retention. All in all, engagement and cognitive load are inherently relevant, and interactive features provide video with segmentation that works out for both.

5.2. H_2 Interactive H5P video experiment with a hidden profile task would increase collaboration compared to simple interactive or raw video

Statistical analysis of the survey responses about collaboration and communication moderately supports the hypothesis H_2 about increased collaboration in the branching scenario video experiment. There was a substantial boost in collaboration compared to the simple interactive video, nevertheless, the difference with the raw video did not reach statistical significance.

Increased collaboration in the hidden profile task was expected, and interactive H5P branching scenario showed appropriateness for creating one. Unlike in the raw or the simple interactive video experiment, the branching scenarios were designed such that each student could only access half of the measurements but could collect the other half from a partner to complete the task. Information asymmetry must have created a condition for positive interdependence, which is known as a pivotal aspect for collaboration (Laal, 2013).

Collaboration in the simple interactive video was remarkably lower than for the raw or branching video. This decrease in collaboration compared to the raw video was unexpected; however, it can be explained with the increased exchange options from interactive H5P features that removed uncertainties from the experiment and thus the need for discussion. A review on educational hypervideos (Sauli et al., 2018) outlines they are more often used individually than in groups.

The observed variations can be analyzed in terms of internal and external script from the theory of guidance in CSCL (Fischer et al., 2013). Collaboration in the raw and interactive video experiment may have occurred by different mechanisms. Students working with the raw video applied their previous experience with similar tasks to recreate an internal collaboration script. Students had previously worked with simple interactive video, so they also might have an internal script for it (that the task can be done individually). Only those working with the branching scenario video had it for the first time, which can naturally lead to more communication. In addition, their collaboration was prompted by an external script from the video annotations. Theoretically, internal collaboration script is superior to external one (Fischer et al., 2013). This shows two possibilities for an educational technologist making collaborative video experiments – continue producing raw videos or create more branching scenario videos with a fading external script to induce internally driven collaboration. The latter is more demanding in terms preparation but would be beneficial for authentic experience simulations. Optimal learning outcomes are expected when involving students in co-creation of interactive H5P simulations (Killam & Luctkar-Flude, 2021).

5.3. Analyzing the relationship between collaboration and flow

This study did not provide enough statistical evidence for correlation between collaboration and flow, but the tendency can be analyzed. From the calculated Pearson's correlation coefficients $r > 0$, there might be positive correlation between collaboration and flow, more prominent in Group C. A negative relationship was expected, as in the previously reported empirical study (Cattaneo et al., 2018) a hypervideo-based collaborative scenario task resulted in lower flow compared to an individual or a teacher-guided scenario.

The apparent contradiction between the two studies may be due to dissimilar participants and tasks. Vocational school students were relatively younger, worked in groups of four, and the task was collaborative co-creation of an interactive video onsite. The present study assessed university students working online in groups of two, collaboration was pre-scripted and provoked by a hidden profile in the design of interactive video experiment. Using positive interdependence strategies in online learning has previously shown to foster university student engagement and good attitudes (Nam & Zellner, 2011). Besides, group size and student age may have an effect on collaboration perception. For instance, it has been shown to improve in smaller group and elder age for kids working on asymmetric online simulation tasks (Rannastu, Siiman, Mäeots, Pedaste, & Leijen, 2019). This could explain why both collaboration and flow were managed relatively high in the interactive video experiment with a hidden profile task.

5.4. Outlining students' preferences for online experimentation

Students accept the technology of raw and interactive video for online experiments. Still, they seek ways to manage cognitive load (e.g., by having embedded instructions, more time) and request higher resolution in video experiments. Making experiments as realistic as possible was one of the principal criteria for an online laboratory (Potkonjak et al., 2016). Whilst a lifelike view could be achieved by the mastery of the filmmaker and the technology, cognitive aspects must be assessed from the perspective of learning theories. In short, multimedia learning strategies to avoid cognitive overload should be considered in experiment design. Embedding instructions and feedback, chunking video into segments and providing students with navigation control could fulfil student preferences, they are in line with the previously overviewed multimedia learning strategies (Mayer & Moreno, 2003) and good educational video practices (Brame, 2016).

6. Conclusion

Interactive H5P technology was successfully applied to enhance an online video experiment. It was found that interactivity influence student collaboration and flow. Simple interactive features added to raw video improved the flow but impeded naturally occurring collaboration. Adding interactive branching scenario with a hidden profile task allowed for recovering collaboration whilst keeping the flow high. The research provided empirical evidence on using H5P video in online physics experimentation at university level, and suggested ways how to manage learning experiences with various interactive features. The design of a video experiment must follow multimedia principles to balance cognitive load, which turns out to be a central factor for an optimal experience.

The present study has several limitations. The research was designed and conducted in a time period restricted by the 1-year EdTech master's program. Convenience sampling was applied to collect data from 68 students at one institution. The researcher also acted as a teacher in an authentic study environment, which might have introduced bias in her judgements. Participant number, age, gender and knowledge balance could be optimized by utilizing random sampling for a larger scale study with several online laboratory works (in physics or other subjects) and teachers. In addition, the used survey instrument blends items from a few research-based instruments; more advanced statistical analysis could be performed towards full validation of the instrument.

Working on the thesis gave useful insights into online laboratories and educational video technology from the perspective of learning theories. The gained knowledge can be directly applied for designing new study materials as a professional educational technologist. Moreover, it holds promise to become an inspiration for further research on online laboratories. It would be exciting to explore possibilities of interactive branching scenario videos for creating online collaborative experiences. Essential would be to investigate impact of interactive video experiments on other learning outcomes, such as conceptual understanding, and compare the use of video experiments in various scenarios and study modes, towards an online physics laboratory promoting 21st Century skills.

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Finally, my biggest gratitude is to my family and Tom for looking after me.

Author's declaration

I hereby declare that I have written this thesis independently and that all contributions of other authors and supporters have been referenced. The thesis has been written in accordance with the requirements for graduation theses of the Institute of Education of the University of Tartu and is in compliance with good academic practices.

Jelena Kosmaca

June 3rd 2022

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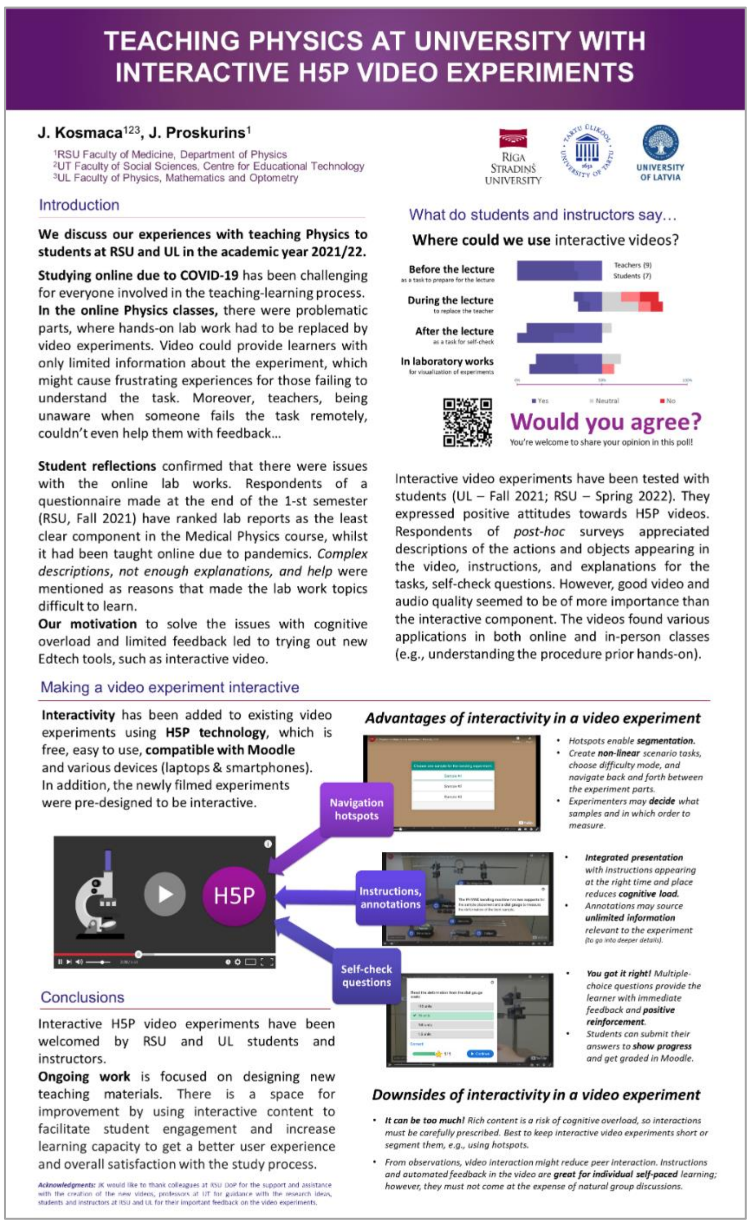
Appendix 1. Conference presentations

Results of preliminary research for this thesis work were presented at two conferences:

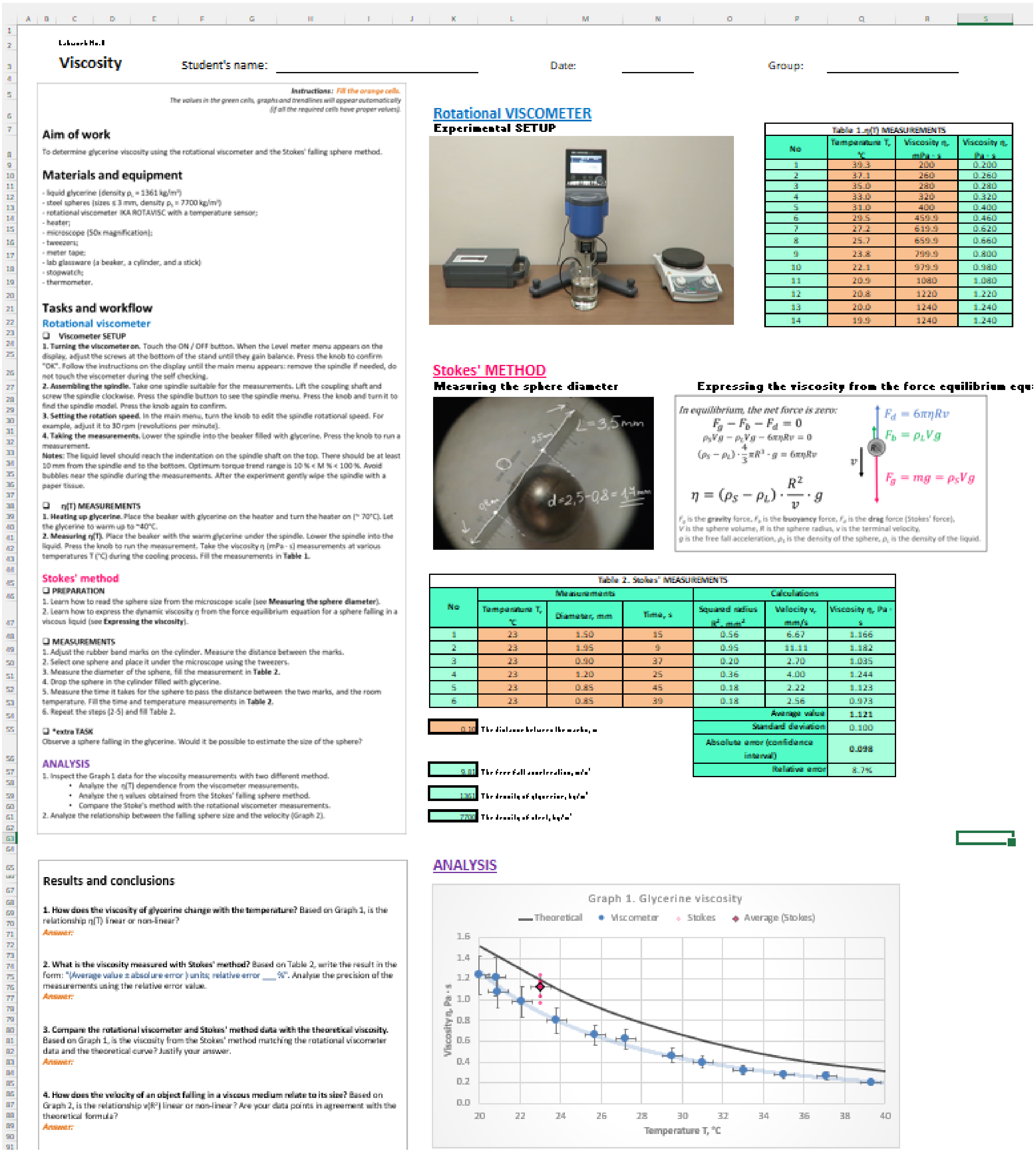
Kosmaca, J. (2022 February 2). *Interactive H5P videos for physics classes* [Conference presentation], UL International 80th Scientific Conference, Seminar for University Physics Education Practitioners “Physics. Education. Practice.”, Riga, Latvia

Kosmaca, J., & Proskurins, J. (2022 April 28-29). *Teaching Physics at University with Interactive H5P Video Experiments* [Conference poster], RSU International COVID-19 Conference “Impact, innovations and planning”, Riga, Latvia



Appendix 2. Fragment of the lab report template

The template is filled with measurement data from the video experiment.



Appendix 3. Self-report questionnaire

Survey about the "Viscosity" video experiment

Informed consent

The survey could take about 5 minutes of your time, it is voluntary and anonymous. The aim of the survey is to study student experience with video-experiments. The results of the survey are planned to be used in research on the use of digital tools in physics training. Your answers may be part of a collection of data that may be published in the future, for example, in a master's thesis. By submitting answers to this survey, you agree that your answers will be stored and processed by Jelena Kosmaca. You can ask for clarification by writing to jelena.kosmaca@gmail.com.

1. Challenge and skills

You have just performed a video-experiment about viscosity measurements by a viscometer and the Stokes' method. Please rate the challenge and your skills for the **Stokes' METHOD part.**

	Too low		Just right		Too high
1.1. How challenging did you find the Stokes' METHOD?	○	○	○	○	○
1.2. Were your skills appropriate for understanding the Stokes' METHOD?	○	○	○	○	○

2. Flow

Please, rate your agreement with the following statements about your experience with **the whole video-experiment.**

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
2.1. I felt in control of what I was doing.	○	○	○	○	○
2.2. I was absorbed intensely by the video-experiment.	○	○	○	○	○
2.3. I found the video-experiment enjoyable.	○	○	○	○	○
2.4. I thought about other things.	○	○	○	○	○
2.5. I found the video-experiment interesting.	○	○	○	○	○
2.6. I was frustrated by what I was doing.	○	○	○	○	○
2.7. The video-experiment bored me.	○	○	○	○	○
2.8. I was aware of distractions.	○	○	○	○	○
2.9. The video-experiment excited my curiosity.	○	○	○	○	○
2.10. I knew the right thing to do.	○	○	○	○	○
2.11. It required a lot of effort for me to concentrate on the video-experiment.	○	○	○	○	○

3. Ease of use

Please, rate your agreement with the following statements about your experience with **the whole video-experiment.**

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
3.1. Overall, I found the video-experiment easy to use.	○	○	○	○	○
3.2. Learning to operate the video-experiment was easy for me.	○	○	○	○	○
3.3. The video-experiment provided me with clear instructions on what to do.	○	○	○	○	○

4. Collaboration

Please, rate your agreement with the following statements about **your pair work*** during the video-experiment.

**Skip this section if you did the experiment all alone*.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
4.1. I was encouraged to discuss elements of my investigation with groupmate	○	○	○	○	○
4.2. I was encouraged to reflect on what I was learning	○	○	○	○	○
4.3. I was encouraged to contribute my ideas and suggestions during discussion	○	○	○	○	○
4.4. I was encouraged to help groupmate collect and analyze data	○	○	○	○	○
4.5. I was encouraged to provide constructive criticism to groupmate and challenge each other's interpretations	○	○	○	○	○
4.6. I was encouraged to share the problems I encountered during my investigation and seek input how to address them	○	○	○	○	○

5. Additional information

5.1. Which options did you use **for communication** with your groupmate?
Please, select all that was used during the video-experiment.
**Skip this section if you did the experiment all alone.*

- ☐ Chat
- ☐ Microphone
- ☐ Web-camera
- ☐ Screen sharing
- ☐ Other

5.2. A place for additional comments and feedback in free form.

Appendix 4. Student feedback responses in free form

Responses from Group A (raw video)

1	"I would like to have the instructions maybe written out in the experiment or circled what is important for doing the tasks at hand"
2	"I was rather distracted - we have our Latin midterm next period, so that was on my mind."
3	"the video was clear and it was easy to fill in the table. It was overall a good experience"
4	"It was really hard to read the data when numbers were flashing on and of all the time. It was also hard to read the values in the other method because the particles were so small and the measuring thing was so far. But this video had better overall quality than previous videos."

Responses from Group B (simple interactive video)

5	"my opinion would not contribute to the second part of the survey regarding groupwork as there was no time left to discuss after taking measurements :). overall good experience"
6	"very hard to see the balls in the liquid"
7	"The video quality was better than that of the other interactive video experiment we did before!"
8	"At Stokes Method it took a long time until the ball reached the red line. As it was hard to see on the screen, maybe there can be made some adjustments. I really liked the interactive part of the video in the start of the setup making sure that I understood it correctly."

Responses from Group C (branching scenario with a hidden profile task)

9	"very good!"
10	"My group did not know there were two parts to the second video, some clarification would be helpful:)"
11	"Great experimental video. Really good for learning. Could use a bit more time in the breakout rooms."

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