**BoostEdu Case study - University of Agder**
**Improving students' learning from educational videos with the help of eye tracking**

## Abstract/Introduction

In this study we combined both quantitative methods based on the analysis of the data obtained by using iMotions 9.3 software and qualitative methods that use open-ended answers to the questionnaires and analysis of pre- and post-tests with mathematical tasks. The methodology included collection of demographic data about participants' mathematical background and learning preferences, work on pre-test mathematics problems, watching short educational videos and working on similar post-test mathematics problems, answering the open-ended post-experiment questionnaire.

The most important conclusions from this study are: (a) videos should be relatively short but informative, preferably with many examples; (b) videos should be dynamic with the presenter highlighting or underscoring text, and commenting in the margins; (c) theory should be presented at a right pace and illustrated with examples; (d) instructor's face should be visible in videos for students' engagement, more trust in the material, and creation of presenter's social presence and human contact; (e) students' feedback on video materials is very helpful for their redesign and improvement.

## Motivation/Goal/Starting point

Educational research provides different, sometimes opposite opinions on the effectiveness of traditional face-to-face (F2F) teaching and fully online (FO) one. Some authors found that in general FO was at least on par if not better than traditional classroom-based face-to-face instruction (Means, Toyama, Murphy, Bakia, and Jones, 2009) while others argue that undergraduate F2F classroom is more efficient in comparison with FO teaching. Xu & Jaggars (2011) argue that "online instruction …, at least as currently practiced, may not be as effective as face-to-face instruction" and "institutions may need to devote substantially more resources to developing and evaluating programs and practices explicitly designed to improve such students' retention and learning in online courses."

The divergence in opinions might also reflect the specific nature of different disciplines. For example, in mathematics, many arguments were provided to support the claim that efficient teaching of mathematics fully online is difficult (Engelbrecht and Harding, 2005; Glass and Sue, 2008; Lokken, 2011; Smith and Ferguson, 2005), yet some authors argued that the use of virtual learner identities in FO teaching can promote a deeper and richer conceptual understanding of mathematical ideas (Rosa and Lerman, 2011). A substantial review of FO undergraduate mathematics teaching was published just ahead of pandemics by (Trenholm, Peschke and Chinnappan, 2019) concluding that "from multiple perspectives, FO mathematics instruction has not been successful in comparison with traditional F2F mathematics instruction.” Furthermore, “FO instruction is still relatively young and challenges are to be expected alongside opportunities for pedagogical transformation.

Prior to Covid-19 pandemics mathematics instructors tried internet-based instruction structured as “blended learning” or “flipped learning” with parts of learning material delivered through the web and supported either with F2F instruction in the class, or FO tutoring, or a mixture of both. However, the proportion of mathematics teachers prepared for FO teaching was low, and a very rapid transition from face-to-face physical teaching to online one in March 2020 initially caused a lot of troubles at various levels, both technical and related to the selection and delivery of material. An extraordinary situation with the COVID-19 pandemic forced higher education institutions (HEI) to move fast to online education. Although teaching staff started rapidly adapting teaching materials developed on-site for the on-line use, “it is important to note the distinction between the resulting ‘emergency remote teaching’ and ‘online learning’ – namely, emergency remote teaching involves transforming on-site classes to a virtual mode, without making changes to the curriculum or the methodology” (Farnell, Skledar Matijević, and Šćukanec Schmidt, 2021).

Despite all HEI efforts to provide good learning opportunities, students were facing serious challenges. “Almost half of all students believed that their academic performance changed for the worse since on-site classes were cancelled and more than half of the students surveyed reported having a larger workload since the transition to online teaching. … Finally, the experience of studying during the COVID-19 pandemic also resulted in new challenges to students psychological and emotional well-being, with students often faced with negative emotions such as boredom, anxiety, frustration and anger” (Farnell et al., 2021). Globally, “the crisis raises questions about the value offered by a university education which includes networking and social opportunities as well as educational content. To remain relevant, universities will need to reinvent their learning environments so that digitalization expands and complements student-teacher and other relationships” (Schleicher, 2020). On the other hand, “the COVID-19 pandemic has provided an opportunity to reflect critically on how higher education is organised and delivered, and to prepare creative solutions and alternative possibilities for future directions in higher education” (Farnell et al., 2021).

FO education provides the potential for major pedagogical innovation in mathematics since online instruction can disrupt traditional teaching processes to the benefit of students and their learning (Borba et al., 2016; Trenholm, Alcock, & Robinson, 2016). Relative student anonymity helps students feel less threatened as compared to live F2F settings (Smith, Ferguson, and Caris, 2003). Furthermore, the use of technology-enabled peer assessment processes takes advantage of the predominantly asynchronous nature of current FO instruction and can help students engage in higher-level mathematical activities and increase student interactivity (Trenholm et al., 2019). According to the analysis of 73 publications, “the main form of teaching during the pandemic at European universities was via live-streamed lectures in real time (74.6 %), presentations sent to students (44.5 %) and asynchronous pre-recorded lectures available online via video (32.1 %) or audio (20.6 %)" (Farnell et al., 2021). This demand for high quality efficient educational video materials prepared in advance or produced directly during live online teaching grows continuously. Our motivation in the project was to test different formats of short educational videos in order to evaluate their impact on students' perception of the material and effectiveness of learning.

The role of educational videos has been increasing recently since more instructors acknowledged their efficiency in delivering new information, explaining complex concepts, and providing step-by-step demonstrations of processes or procedures. Nowadays, educational videos come in different formats which can be characterized into the following categories, even though there might be an overlap between them.

*Instructional videos* provide direct instruction on a specific topic or concept. The instructor/presenter can organise and explain the content using visuals, diagrams, or animations to enhance understanding, build conceptual understanding and promote critical thinking. *Demonstration videos* are often used in STEM disciplines where direct demonstrations show how to perform a specific task or experiment. They can be effective for illustrating procedures, showing practical applications of concepts, and providing visual representations of real-world scenarios. *Interactive videos* provide opportunities to interact with the video content through a variety of tools for interaction. Users can click, drag, scroll, hover, gesture, etc. to interact with the video's content similarly to the interaction with the web content. Quizzes or polls can be embedded within the video allowing learners to actively engage with the content and assess their own learning progress.

*Conceptual videos* focus on the explanation of abstract or complex concepts in a variety of ways, including both simplified, intuitive explanations and rigorous step-by-step ones. Visualisations, animations, unusual analogies may be used to facilitate learning, stimulate curiosity and interest in the topic. *Problem-solving videos* present detailed examples of solutions to different problems explaining how learners can apply their knowledge and skills to solve problems. They can be effective for developing problem-solving skills, critical thinking, and decision-making abilities provided that learners combine them with their own problem-solving efforts. *Documentary-style videos* can be used to provide historical facts explaining the development of mathematical tools and ideas. They can also highlight examples of real-world applications of mathematics helping the learners to connect theory to practice and better understand the real-world applications of the material.

Mayer, Fiorella, and Stull (2020) concluded that people learn better when (1) the onscreen instructor draws graphics on the board while lecturing (dynamic drawing principle), (2) the onscreen instructor shifts eye gaze between the audience and the board while lecturing (gaze guidance principle), (3) the lesson contains prompts to engage in summarizing or explaining the material (generative activity principle), (4) a demonstration is filmed from a first-person perspective (perspective principle), or (5) subtitles are added to a narrated video that contains speech in the learner's second language (subtitle principle).

Watching educational video materials, students may pay attention to various aspects including the following. *Content*: ideally, we expect students to focus on the concepts, ideas, factual information, techniques and skills along with supporting details conveyed through the video. *Visuals*: visual elements of the video - graphics, diagrams, animations, demonstrations - can help students understand complex concepts and processes and enhance engagement with the material. *Audio*: the voice, intonation, (possibly) accent of the presenter or narrator, presence of the background music and sound effects may impact students' understanding of the spoken content and an overall impression of the video both positively and negatively. *Pace and flow*: students' comprehension, attention, and engagement with the video may be affected by the pace and flow of the video, including the speed of the content delivery, transitions between different topics or sections, and overall organization. *Visual cues*: text highlights, annotations, callouts that emphasize important points, key terms, or relevant details can help students identify and focus on essential information in the video. *Interactivity*: interactive elements (quizzes, polls, interactive on-screen simulations) facilitate students' active engagement with the material and allow them to test their understanding by applying acquired knowledge. *Presenter's style*: presenter's speaking tone, body language, presentation skills can impact students' engagement, perception of the content, and motivation for study.

**Background of the case study**

University of Agder (UiA) is a public university located in the southern part of Norway on two campuses, in Kristiansand and Grimstad, about 45 kilometers away. Although UiA is one of the youngest universities in Norway, its history can be traced back to 1839 when the Teacher Training School was established. The university is the home to about 13,000 students and 890 academic staff and is organised in six faculties: Faculty of Engineering and Science, Faculty of Fine Arts, Faculty of Health and Sport Sciences, Faculty of Humanities and Education, Faculty of Social Sciences, School of Business and Law and has a Teacher Education Unit. Most students study in Kristiansand and engineering education is based in Grimstad where specialized laboratories and research centres are located.

The University of Agder has Norway's longest running master programme and the largest PhD programme in mathematics education and is acknowledged as one of the national leaders in the field. University of Agder hosts the Centre for Research Innovation and Coordination of Mathematics Teaching (MatRIC), the only National Centre for Excellence in Education specialised in teaching mathematics. MatRIC is funded by NOKUT (the Norwegian Agency for Quality Assurance in Education), an independent expert body under the Ministry of Education and Research and receives financial aid from the university. Mathematics is taught at UiA within the Faculty of Engineering and Science as a service subject with the largest cohorts being engineering students on the campus of Grimstad, economics students and teacher candidates in Kristiansand. Student population is heterogenous with quite diverse backgrounds and attitudes to learning mathematical disciplines; class sizes differ significantly ranging from 3-4 students in advanced mathematics courses to more than 400 students in the first-year courses for future engineers.

**Case study rationale**

The case study was not designed with a particular course in mind and the main purpose was to learn more regarding students perception of different video formats and their impact, if any, on student learning. The initial idea was to test many more video formats, from simple videos taken by a mobile phone to videos produced with specialized video editors like Camtasia, Kaltura, or Vmaker to videos taken in a professional studio available at the University of Agder. In fact, the first two five-minutes long educational videos were taken at the studio at UiA. The videos taken in the studio allow one to show an upper body of the instructor standing next to a large smart screen where either the slides can be shown, or the text and formulas can be written. A high-resolution camera can zoom instructor's face in and out either keeping the instructor within the video or zooming in the screen.

This format allows more instructor gestures and ensures good eye contact when the camera zooms the instructor's face in, but the process of making a short video takes a lot of time and requires assistance of colleagues for the smooth running. For example, help is needed to show the text to the presenter behind the camera in order to keep presenter's eyes focused on the camera and thus establishing good eye contact with students who will watch the video. Although the camera settings can be adjusted so that presenters are placed in the video according to their preferences and the camera zooms in or out automatically, presenters still need to give quick looks at the panel which switches different modes and, without assistance, they lose eye contact with the audience and material for some time. Considering that the project team was striving to make high quality video materials, a substantial effort was required from three people (including the presenter). Timewise, one superior quality video may require several hours of continuous work with short breaks. After some practicing, videos need less time although external support for presenters is still needed.

This is why the project team decided to run the main study using the videos recorded in a natural environment used by a wide majority of mathematics teachers – Zoom session. Many of our colleagues send links to online classes via university learning management systems (LMS) and we decided to make short educational videos for the main study in the format of standard video recordings of lectures with the same mathematical content but presented differently and with and without lecturer in a video.

**Methodology**

Since much of the teaching currently offered at UiA and partner universities is online, it is especially important to arrange it so that students actively engage in learning during the lectures, seminars, and tutorial sessions. This is a serious challenge which requires thorough testing of different teaching formats and their impact on students learning and retention of knowledge. To this end, we wanted to use both traditional qualitative methods (interviews, questionnaires, tests) and novel quantitative methods using eye-tracking technology.

Modern technological advancement suggest the use of eye-tracking equipment as an efficient tool for analysing students' learning. Huntanu & Bertea (2019) argued that "one of the most accurate methods to record user behavior is through eye tracking technology. … The human gaze can tell exactly what has been seen, in what order and for how long and, on the other side, what has been missed. Therefore, eye tracking data gives valuable insights for improving the learning process. Moreover, eye data can reveal valuable information about the emotional and cognitive processes of the student." We also paid particular attention to the organization of the experiments with the eye-tracking equipment guided by "a list of threats to the validity of eye-movement research … which will allow researchers to identify problems before conducting their studies" (Orquin & Holmqvist, 2018).

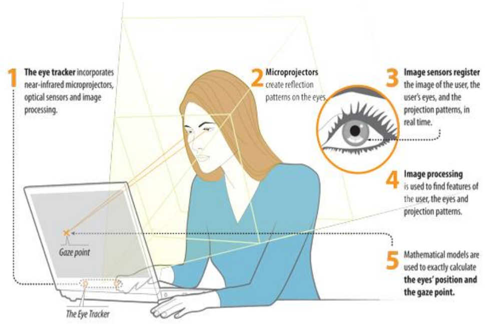
When eye tracking is used in educational research, it is important to ensure data reliability by using equipment with technical characteristics that satisfy the research standards. In our experiments the following hardware was used.

**Notebook Dell XPS 17 9710**
Processor family: 11th Generation Intel® Core™ i7-11800H (24 MB Cache, 8 Core, 2.30 GHz)
Processor model: Core™ i7-11800H
Display diagonal: 17-inch, UHD+ 3840 x 2400, 60 Hz, anti-reflective, touch, Adobe 100% min; DCI-P3 99% type, 95% min, 500 nits, wide-viewing angle
HD type: Ultra HD
Display resolution: 3840 x 2400
Internal memory: 32 GB
Internal memory type: 32 GB, 2 x 16 GB, DDR4, 3200 MHz, integrated
Total storage capacity: 1 TB, M.2 2280, PCIe NVMe Gen3 x4, D3, SSD
Storage media: SSD
On-board graphics adapter model: Intel UHD Graphics
Operating system installed: Windows 10 Pro

**Eye tracker Tobii® Pro Nano**
Eye tracking technique: Video-based pupil- and corneal reflection eye tracking with dark and bright pupil illumination modes. One camera captures images of both eyes for accurate

measurement of eye gaze and eye position in 3D space, as well as pupil diameter. Binocular eye tracking.
Precision: 0.10° RMS at optimal conditions
Blink recovery time: 1 frame (immediate)
Data output: Timestamp, Gaze origin, Gaze point, Pupil diameter
Sampling frequency: 60 Hz
Accuracy: 0.3° at optimal conditions
Eye tracker latency: 1 frame (17 ms)
Gaze recovery time: 250 ms
Tracker and client time synchronization: Integrated between the eye tracker time domain and the client computer time domain.

The use of eye tracking for collecting data is illustrated in the following diagram.




There is a strong motivation to relate the information about where and for how long a person looks to cognitive processes beyond attention, including memory, language, perception, and decision making. A fixation is defined as a period of time during which the eyes are fixed on a visual object; fixations very in length lasting in general between 180 and 330 milliseconds. Saccades are eye moves from one fixation to another one; they vary in duration and size lasting in general between 30 and 50 milliseconds. (Carter & Luke, 2020). The following metrics are among the most frequently used in the eye tracking experiments:

*Ratio*: percentage of respondents who looked at the area(s) of interest (AOI) at all
*Time to first fixation* (TTFF)/ hit time: time lapse until the AOI was seen the first time
*Dwell time*: time spent looking at the AOI
*Fixation counts and average duration of fixation*: How many fixations it took to take in information, and how long they were
*Revisits*: How often respondents looked back to the AOI

In this study we combined both quantitative methods based on the analysis of the data obtained by using iMotions 9.3 software and qualitative methods that use open-ended answers to the questionnaires and analysis of pre- and post-tests with mathematical tasks.

We report only part of the results; a detailed analysis of the experiments will be reported in a research paper which is being prepared for publication.

A brief description of the methodology:
- informing participants, signing consent letters, calibrating the eye tracker
- collecting demographic data about participants mathematical background and learning preferences in a multiple-choice questionnaire
- participants solve pre-test mathematics problems
- participants watch short educational videos with the same mathematical content but in different formats
- participants solve post-test mathematics problems
- participants answer post-experiment open-ended questionnaire
- quantitative data are processed by iMotions 9.3 software and qualitative data are analysed
- conclusions are made
- recommendations are disseminated to higher education institutions.

**Design**

There is no one-size-fits-all answer to the question regarding the effectiveness of video materials in learning because it depends on a variety of factors, such as the content being taught, the target audience, and the instructional goals. Empirical research suggests that the presence of a lecturer in videos can have certain advantages in facilitating learning. Having a lecturer in a video can provide a sense of human connection, engagement, and social presence, which can enhance students' motivation and interest in the content. In particular, lecturers can use nonverbal cues, such as facial expressions and gestures, to attract learners' attention and emphasize important points. On the other hand, well-designed videos with slides, writing, and other visual aids, such as diagrams, animations, and simulations, can still be effective in facilitating learning, especially when combined with other instructional strategies, such as active learning activities, formative assessments, and opportunities for student reflection and discussion.

Another important aspect of F2F teaching is eye contact between the instructor and students, especially in small and medium-size classes. Eye contact should be used in a purposeful and intentional manner, correspond to instructional goals and facilitate learning. Several aspects of eye contact should be taken into consideration in educational videos. First, eye contact can help capture students' attention and increase their engagement with the video content. However, in mathematics videos attention to written text and formulas is important, and presenters can assist learners by indicating with their head and eye motions the direction in which the learners should look. Second, repeated use of eye contact can convey a sense of social presence, making students feel more connected to the material and the lecturer, which can impact their motivation and willingness to engage with the content.

Third, eye contact between the lecturer and the students can convey confidence, sincerity, and trustworthiness. This can influence students' perception of the lecturer's expertise which in turn can impact their level of trust in the information being presented. Finally, eye contact can evoke emotional responses in students, such as a sense of being understood, acknowledged, or appreciated. This emotional connection with the lecturer may impact students' attention, to the information, its processing and retention. We encouraged the presenter to maintain now and then eye contact with learners.

Since in some cases videos with slides and writing may be sufficient, while in other cases, the presence of a lecturer may be beneficial, we decided to test both options in our videos. Considering that learner preferences and learning styles may vary, we believe that it is important to consider the diverse needs and preferences of the target audience when designing instructional materials.

In general, the design of the experiments with eye tracking includes the collection of the following data.
(1) Demographic information (age, gender, educational background).
(2) Participants' prior knowledge of the mathematics content presented in videos through multiple-choice or open-ended questions.
(3) Participants' preferred learning style (visual, auditory, kinesthetic, etc.), preferred study strategies, and preferred types of instructional materials.
(4) Participants' level of interest, motivation, and perceived relevance of the experiment.

First our team recorded two pilot videos at a semi-professional studio at UiA. Both videos are around five minutes long, on the same topic, and with the same material on the slides. The only essential difference is the presence or no presence of the instructor in the video (video #1 without instructor's presence and with the instructor in the video #2).



In the very beginning, we collected demographic data (age and gender) through the iMotions software. In addition, each participant had to answer a questionnaire providing data on their mathematics background. To test the efficiency of educational video, pre- and post-tests were designed for the participants with three similar tasks in both tests.

The organization of the experiment was as follows. Participants were divided in two groups (one male and one female in each group). Each group went through the software calibration process, read the following slide with the description of the experiment and all necessary information.

**Thank you very much for taking part in our pilot project!**
**Please read this message carefully.**

**This test has 4 parts.**
**Part 1: five multiple choice questions about your background (30 sec per question).**
**Part 2: three multiple choice mathematics questions (120 sec per question).**
**Part 3: an educational video.**
**Part 4: three multiple choice mathematics questions (120 sec per question).**

**If you answer faster, please advance to the next slide manually.**

To "clean" the previous images in the stimulus before a new one appears on the screen, slides with a thick black cross on the white background were placed in between.

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Each participant answered the questionnaire regarding their mathematics background (each of the five multiple choice questions was presented on a separate slide).

**Questionnaire**

Q1 How long time ago did you take mathematics course?
- I study mathematics now
- Less than 2 years ago
- 2-5 years ago
- 5-10 years ago
- More than 10 years ago

Q2 At what level did you take mathematics courses:
- Secondary school
- High school
- Bachelor's degree
- Master's degree
- Ph.D. degree

Q3 How often do you use mathematics in your daily life?
- Never
- Seldom
- Often
- Very often
- Almost daily

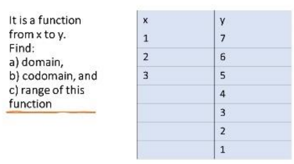
Q4 How would you rate your mathematics proficiency?
- Extremely poor
- Poor
- Average

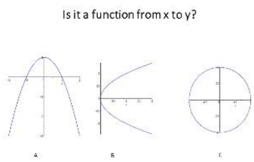
- Good
- Excellent

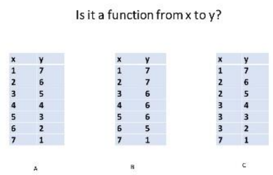
Q5 If you have a university degree, what is your professional background?
- Social sciences
- Education
- Medicine and life sciences
- Natural sciences
- Mathematics and computer science
- Engineering

Then each participant answered the following three pre-test questions.

**Pre-test questions**



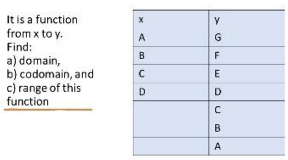



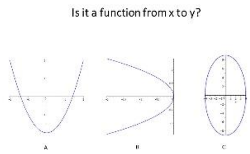

Then each of the two groups watched one of the videos without or with a presenter and answered the following three post-test questions.

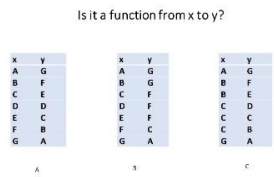


After watching the videos, participants answered the following three post-test questions.

**Post-test questions**



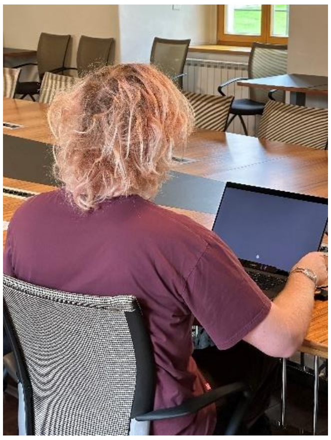

In the very end of the experiment, a slide thanking participants was shown.

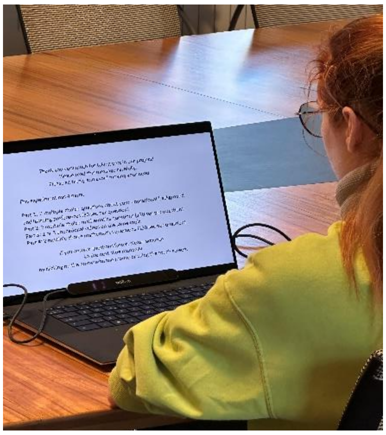
**Thank you very much once again for taking part in our pilot project!**

**Your contribution helps our students to learn mathematics better!**

After the analysis of positive and negative experiences with the first pilot study with videos #1 and #2, we designed another study. Participants were asked to sign a consent form agreeing to the use of their anonymised data for reporting and presentation.

As in the pilot, participants started with the calibration of eye tracking followed by the information slide with the information about the experiment.





This is the text on the first slide participants saw after the calibration process.

Thank you very much for taking part in our project!
Please read this message carefully.

This experiment has 4 parts
Part 1: 7 multiple choice questions about your educational background and learning preferences (30 sec per question)
Part 2: 2 multiple choice mathematics questions (120 sec per question)
Part 3: 3 educational videos on the same topic
Part 4: 2 multiple choice mathematics questions (120 sec per question)

If you answer questions faster, please advance to the next slide manually by clicking on the arrow.

As before, slides with a thick black cross on the white background were placed between all slides with stimuli to “clean” the previous images.

Each participant answered the questionnaire regarding their mathematics background, learning style, preferred study strategies and types of instructional materials (each of the seven multiple choice questions was presented on a separate slide).

**Questionnaire**

Q1 How many university mathematics courses have you taken to date?
- None
- I study the first mathematics course now
- 1-2
- 3-4
- More than 4

Q2 How would you rate your mathematics proficiency?
- Extremely poor
- Poor
- Average
- Good
- Excellent

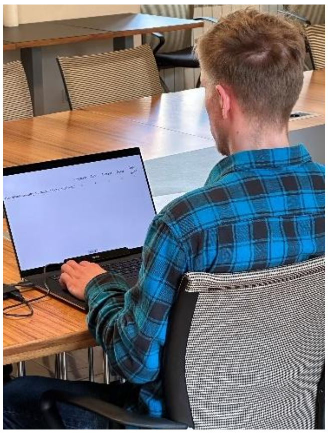
Q3 How often do you use mathematics in your daily life?
- Never
- Seldom
- Often
- Very often
- Almost daily

Q4 Did you take a course in Linear Algebra?
- Yes
- No
- What is Linear Algebra?

Q5 A website has a video showing how to make a special graph or chart. There is a person speaking, some lists and words describing what to do and some diagrams. I would learn most from
- listening
- seeing the diagrams
- watching the actions
- reading the words

Q6 I prefer a presenter or a teacher who uses
- handouts, books, or readings
- demonstrations, models or practical sessions
- diagrams, charts, maps or graphs
- question and answer, talk, group discussion, or guest speakers
- educational videos

Q7 I want to assemble a wooden cabinet that came in parts from IKEA. I would learn best from
- advice from someone who has done it before
- written instructions that came with the parts for the cabinet
- watching a video of a person assembling a similar cabinet
- diagrams showing each stage of the assembly



After the questionnaire, each participant answered two pre-test questions from the following four (Problems 1 and 2 for block 1) and (Problems 3 and 4 for block 2).

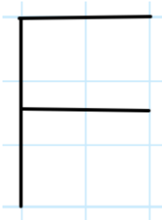
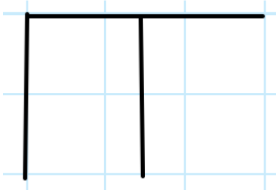
## Pre-test questions

**Problem 1**
What matrix defines the reflection in the line y = -x?

$A)\begin{pmatrix}0 & -1\\ 1 & 0\end{pmatrix}\quad B)\begin{pmatrix}0 & -1\\ -1 & 0\end{pmatrix}\quad C)\begin{pmatrix}-1 & 0\\ 0 & -1\end{pmatrix}\quad D)\begin{pmatrix}0 & 1\\ -1 & 0\end{pmatrix}$

**Problem 2**

Which of the following matrices describes the transformation of the image

 to  ?

$A)\begin{pmatrix}0 & -1\\ 1 & 0\end{pmatrix}$ $B)\begin{pmatrix}0 & -1\\ -1 & 0\end{pmatrix}$ $C)\begin{pmatrix}-1 & 0\\ 0 & -1\end{pmatrix}$ $D)\begin{pmatrix}0 & 1\\ -1 & 0\end{pmatrix}$

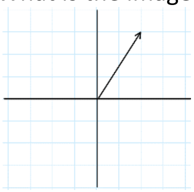
**Problem 3**

What is the image of the vector $\begin{pmatrix}2\\ 3\end{pmatrix}$ under the linear transformation with matrix $\begin{pmatrix}-2 & 0\\ 0 & 1\end{pmatrix}$?

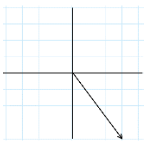
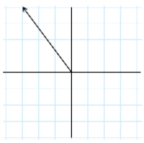
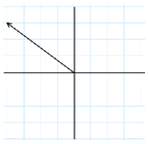
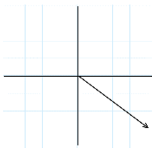
A) $\begin{pmatrix}3\\ -4\end{pmatrix}$ B) $\begin{pmatrix}-3\\ 4\end{pmatrix}$ C) $\begin{pmatrix}-4\\ 3\end{pmatrix}$ D) $\begin{pmatrix}4\\ -3\end{pmatrix}$

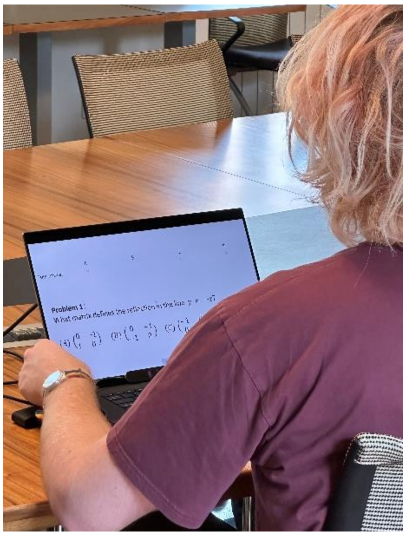
**Problem 4**

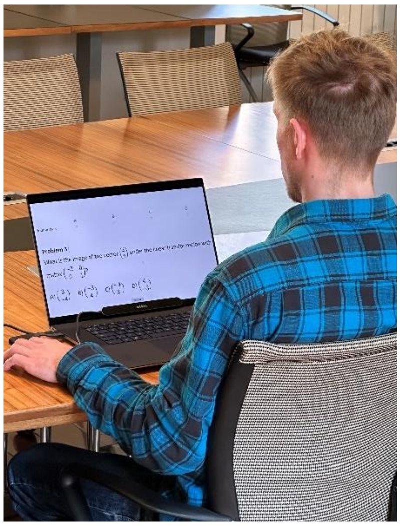
What is the image of the vector



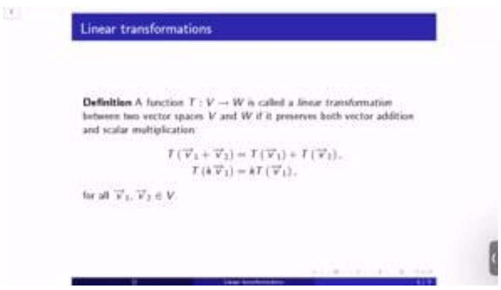
under the linear transformation with matrix $\begin{pmatrix}-2 & 0\\ 0 & 1\end{pmatrix}$?

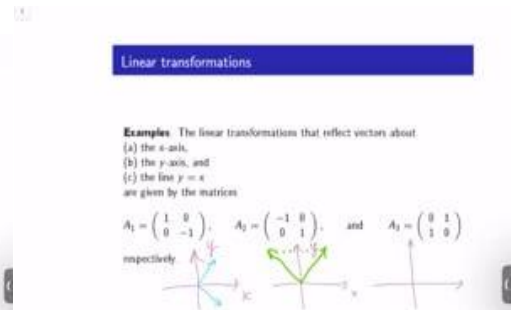
A)  B)  C)  D) 

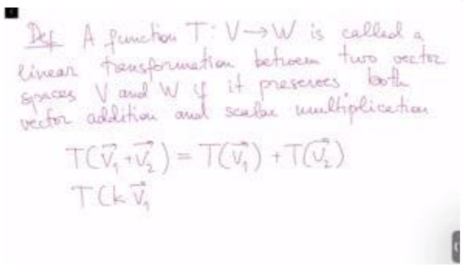


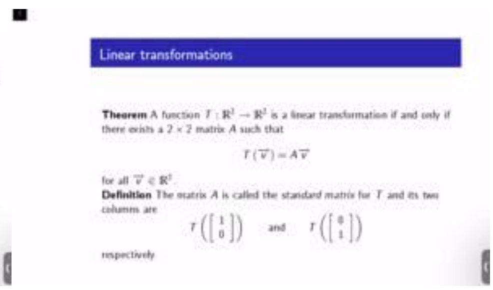


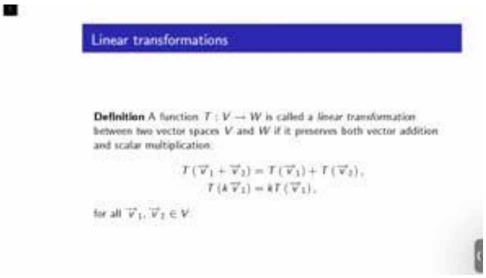
After this pre-test, participants watched two blocks of three videos in different formats (at least one with the presenter and one without a presenter in each block) from the following selection of six videos. Video 1: slides with the presenter's voice (139 sec); video 2: slides with marking and presenter's voice (186 sec); video 3: handwritten mathematics text and presenter's voice (247 sec); video 4: slides with the presenter in a window in the upper right corner (161 sec); video 5: slides with marking and with the presenter in a window in the upper right corner (233 sec); video 6: handwritten mathematics text with the presenter in a window in the upper right corner (447 sec). Videos are uploaded to Vimeo and can be accessed by opening the embedded links (right click of the mouse on the image of the video).

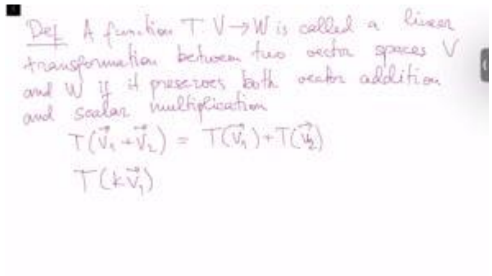


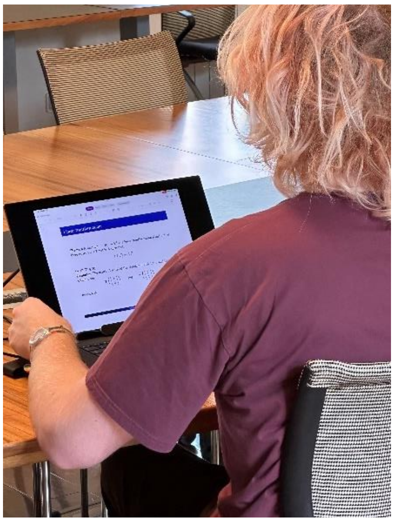



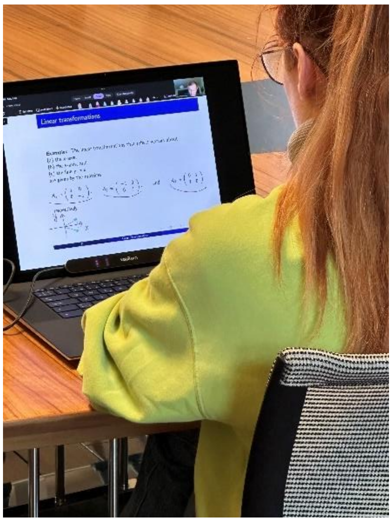





Participants watched videos 1, 2, and 6 (772 sec) in block 1 and videos 3, 4, and 5 (641 sec) in block 2.





After watching three videos, participants in both blocks 1 and 2 answered the following two post-video test questions followed by the final “Thank you” slide.

**Post-test question**

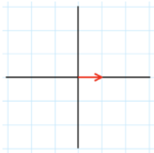
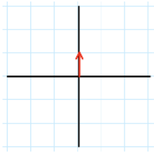
**Problem 5**

Which of the following matrices maps the vectors $\begin{pmatrix}1\\0\end{pmatrix}$ and $\begin{pmatrix}0\\1\end{pmatrix}$ to the vectors $\begin{pmatrix}2\\3\end{pmatrix}$ and $\begin{pmatrix}4\\5\end{pmatrix}$ respectively?

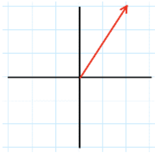
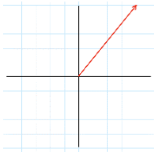
$A)\ \begin{pmatrix}4 & 2\\5 & 3\end{pmatrix}$ $B)\ \begin{pmatrix}4 & 5\\2 & 3\end{pmatrix}$ $C)\ \begin{pmatrix}2 & 4\\3 & 5\end{pmatrix}$ $D)\ \begin{pmatrix}2 & 3\\4 & 5\end{pmatrix}$

**Problem 6**

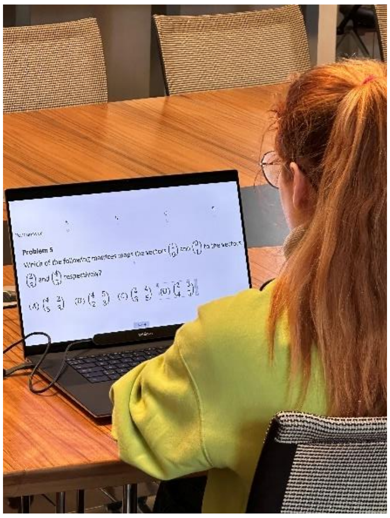
Which of the following matrices maps the vectors

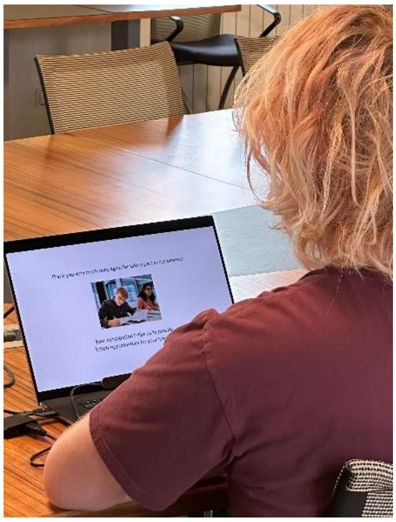
 and 

to the vectors

 and  respectively?

$A)\begin{pmatrix}4 & 2\\5 & 3\end{pmatrix}\quad B)\begin{pmatrix}4 & 5\\2 & 3\end{pmatrix}\quad C)\begin{pmatrix}2 & 4\\3 & 5\end{pmatrix}\quad D)\begin{pmatrix}2 & 3\\4 & 5\end{pmatrix}$





Right after the final mathematics test, participants were invited to answer an open-ended questionnaire regarding their experience.

**Final questionnaire**

Q1 What video did you like the best and what the least, and why?

Q2 What videos were the most and the least engaging, and why?

Q3 How did the videos impact your understanding of the topic?

Q4 Did you find any aspects of the videos particularly helpful or challenging?

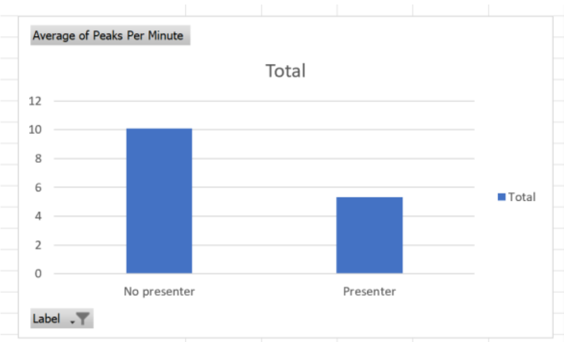
Q5 Do you have any suggestions on how the videos could be improved?

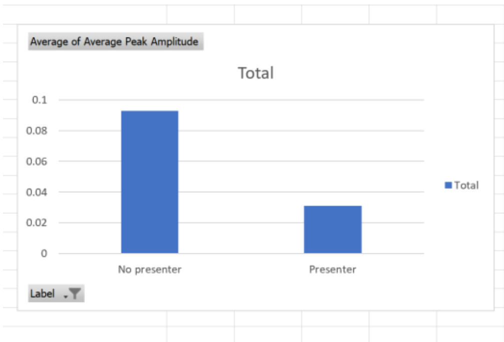
Reflection about the results of the studies and the feedback from the participants follows.

**Experience/Results/Lessons learned**
(how the design worked and what we learned: a designers' perspective)

In the pilot study, Tobii Pro Nano and an internal notebook camera were calibrated to collect facial expressions and eye tracking information from the participants. In addition, we had the possibility to outfit participants with a wrist-based Shimmer GSR+ device, Enobio EEG headset, and Polar HT heart rate sensor. The Shimmer3 GSR+ (Galvanic Skin Response) unit provides Galvanic Skin Response data acquisition (Electrodermal Resistance Measurement – EDR/Electrodermal Activity (EDA). GSR refers to changes in sweat gland activity that are reflective of the intensity of our emotional state, otherwise known as emotional arousal. Measuring EEG is the basis of all mental workload studies and one can deduct the mental state from brain activity using specific frequency bands. In our pilot EEG was used to compare cognitive load of participants watching videos with and without presenter.

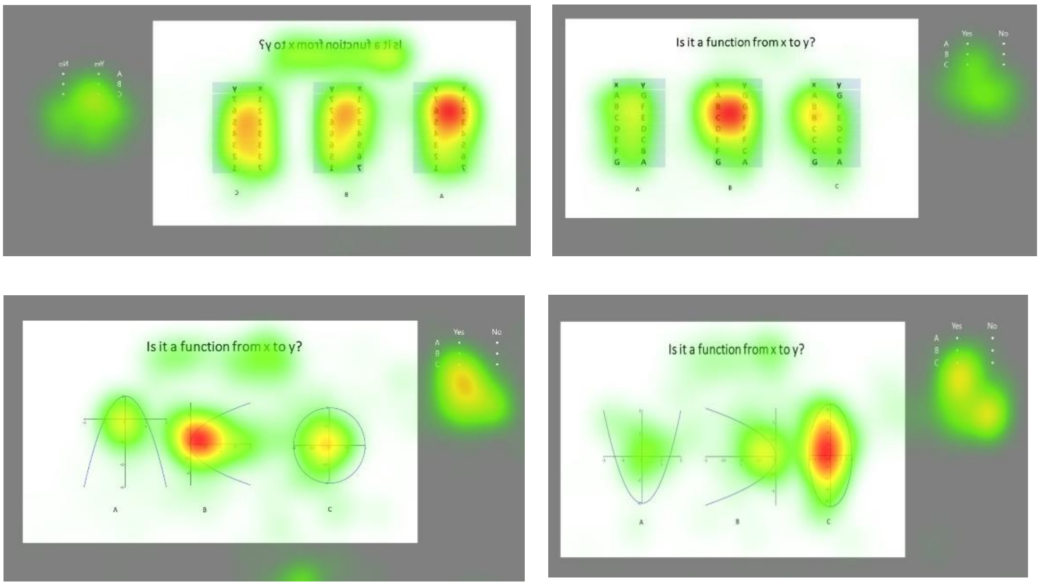
GSR data allowed us to obtain useful information regarding participants emotional state when they watched videos with and without the presenter.



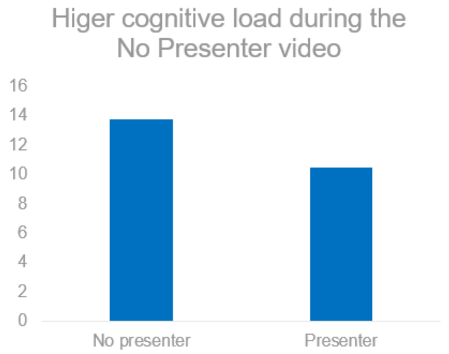



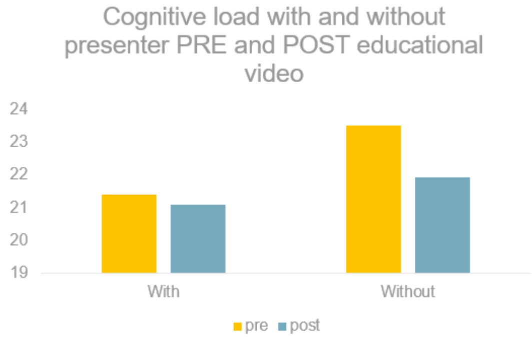
It can be seen from the diagrams that the average number of peaks per minute and their amplitude were higher when there were no presenters in the video. As we argued earlier, the presence of a lecturer in a video can create a sense of social presence, when the lecturer is seen as present and fully engaged in the educational process. This can positively affect learning outcomes by enhancing students' motivation, engagement, and emotional connection to the content. Furthermore, students may feel more connected to the content when they see a real person delivering the instruction.

It was also interesting to compare heat maps of participants when they were engaged with stimuli generated by iMotions 9.3 software. For instance, we observe that participants' attention to a similar mathematics task in pre- and post-tests was focused on different visual stimuli thus signaling the change in understanding after the educational video.

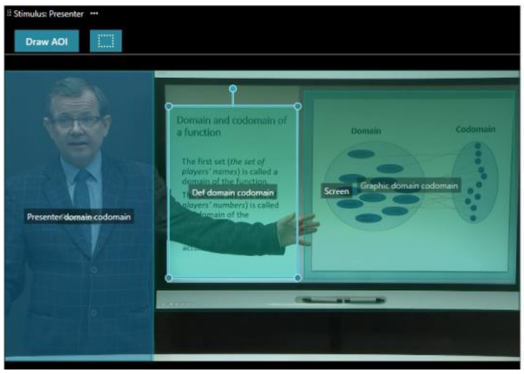



It was also interesting to observe that the cognitive load of participants who watched the video without presenter was higher thus indicating that with the presence of the presenter in the video participants were less engaged cognitively because they "shared" responsibilities for learning with the teacher.



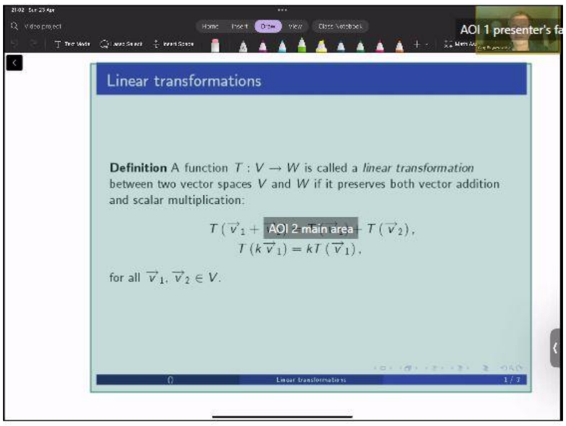

Eye tracking provides a lot of useful data that can be used to analyse participants' response to different stimuli. One of the useful approaches is based on using the areas of interest (AOI) to compare the spread of participants' attention between different elements in a video. For instance, in the pilot the presenter in a video was well visible and was gesturing during the video pointing at some parts of the slides. We were interested in analysing how gesture cues influenced participants watching the video. To this end, dynamic AOI were created as illustrated in the pictures below.

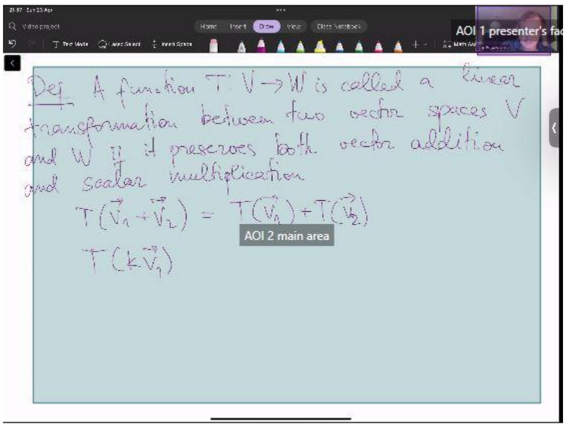




The analysis of the respondents' videos by iMotions provides the following table from which the information regarding the share of attention (both fixations and saccade metrics including fixations, revisits, and saccade count) can be retrieved.

| AOI metrics | Def domain codomain | Graphic domain codomain | Presenter | Presenter domain codomain | Screen | Title |
|---|---|---|---|---|---|---|
| **Information** | | | | | | |
| AOI duration (ms) | 43076.8 | 43076.8 | 264824.9 | 43076.8 | 264824.9 | 5045 |
| AOI duration (%) | 16.3 | 16.3 | 100 | 16.3 | 100 | 1.9 |
| Size (cm2) | NA | NA | NA | NA | NA | NA |
| Size (%) | NA | NA | NA | NA | NA | NA |
| Respondent base | 2 | 2 | 2 | 2 | 2 | 2 |
| **Fixation based metrics** | | | | | | |
| Respondent ratio (%) | 100 | 100 | 100 | 100 | 100 | 100 |
| Revisit count | 10.5 | 10 | 50.5 | 6 | 52 | 3 |
| Fixation count | 45.5 | 55 | 83.5 | 11 | 584.5 | 9.5 |
| TTFF AOI (ms) | 1675.8 | 1063.2 | 532.5 | 14355.6 | 0 | 0 |
| Dwell time (ms) | 13427.5 | 12867.7 | 44476.3 | 4996.4 | 143173.6 | 1870.4 |
| Dwell time (%) | 31.2 | 29.9 | 16.8 | 11.6 | 54.1 | 37.1 |
| First fixation duration (ms) | 105.5 | 93.6 | 199.9 | 966 | 224.4 | 224.4 |
| **Saccade based metrics** | | | | | | |
| Respondent ratio (%) | 100 | 100 | 100 | 100 | 100 | 100 |
| Saccade count | 38.5 | 60 | 64 | 8.5 | 662 | 7.5 |
| Amplitude (deg) | 1.9 | 3.3 | 3 | 2.3 | 4.3 | 2.2 |
| Peak velocity (deg/s) | 71.7 | 91.8 | 87.8 | 64.9 | 114.3 | 77.1 |

During the main study important quantitative data were obtained which, in addition to qualitative data, help to answer important questions regarding the presence of the presenter in videos. The following diagrams and tables illustrate this.



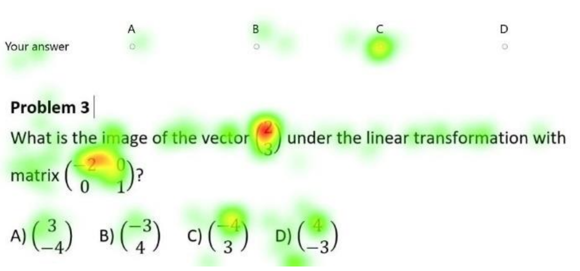



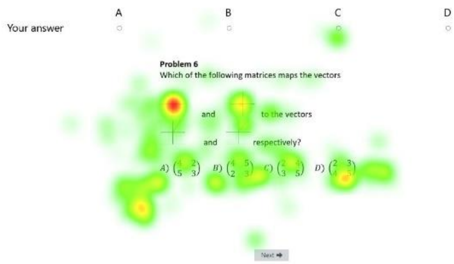
| AOI metrics | AOI 1 presenter's face | AOI 2 main area |
|---|---|---|
| **Information** | | |
| AOI duration (ms) | 160227.7 | 160227.7 |
| AOI duration (%) | 99.4 | 99.4 |
| Size (cm2) | NA | NA |
| Size (%) | NA | NA |
| Respondent base | 2 | 2 |
| **Fixation based metrics** | | |
| Respondent ratio (%) | 50 | 50 |
| Revisit count | 2 | 4 |
| Fixation count | 3 | 423 |
| TTFF AOI (ms) | 1746.6 | 64.5 |
| Dwell time (ms) | 2081.8 | 131968.9 |
| Dwell time (%) | 1.3 | 82.4 |
| First fixation duration (ms) | 483 | 149.9 |
| **Saccade based metrics** | | |
| Respondent ratio (%) | 0 | 50 |
| Saccade count | NA | 441 |
| Amplitude (deg) | NA | 5.1 |
| Peak velocity (deg/s) | NA | 128.5 |

| AOI metrics | AOI 1 presenter's face | AOI 2 main area |
|---|---|---|
| **Information** | | |
| AOI duration (ms) | 444356.7 | 444356.7 |
| AOI duration (%) | 99.4 | 99.4 |
| Size (cm2) | NA | NA |
| Size (%) | NA | NA |
| Respondent base | 2 | 2 |
| **Fixation based metrics** | | |
| Respondent ratio (%) | 50 | 50 |
| Revisit count | 6 | 17 |
| Fixation count | 11 | 803 |
| TTFF AOI (ms) | 127301.8 | 0 |
| Dwell time (ms) | 5129.7 | 390571.1 |
| Dwell time (%) | 1.2 | 87.9 |
| First fixation duration (ms) | 582.9 | 540.9 |
| **Saccade based metrics** | | |
| Respondent ratio (%) | 50 | 50 |
| Saccade count | 5 | 815 |
| Amplitude (deg) | 2.1 | 4.7 |
| Peak velocity (deg/s) | 58.2 | 110.5 |

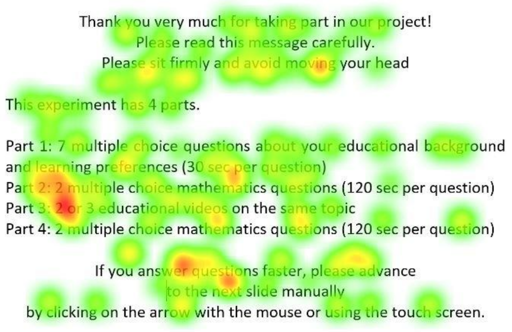
Although respondents mostly paid attention to what happens in the main area, they did fixate on presenter's face watching the videos and revisited it.

Additional useful information regarding students' thinking during the problem solution can be obtained from the heat maps.




Even heat maps of students reading instructions can be helpful for understanding how they perceive information and acquire new knowledge.




**Feedback from students/teachers**
(how the design worked, what they learned and how they felt like: students'/teachers' perspective)

After the first pilot we analysed the feedback from participants (provided in an open-ended format without any guidance questions) and learned that the choice of a football theme for the explanation of the concept of function was perceived differently. We provide reflections of some of participants below. Alberto nicely summarised this idea: "As I am not a football aficionado I was not distracted by a connection to the subject material (players on football teams) but inversely focused a little more attention on trying to understand the football example and how it related to the math lesson. So, it is worth noting that using football may have a different impact on respondents depending on whether or not they are football fans themselves." Indeed, Christine responded that "personally, the video about FOOTBALL is fantastic. It felt easier to dive into the explanation since FOOTBALL is a remarkably familiar concept." On the other hand, Christian explained that "I get easily distracted and shifts attention quickly, e.g., when I saw the players from the French national team, I did not pay attention to what was communicated in the video about the concepts of a function, but instead I just start thinking about the football game in the world cup 2018 and the players etc. So, I did not listen carefully to all the concepts."

There was also feedback on the conditions in the area around the room where the experiment was conducted. Christian confessed that "I suck at quick math especially under "pressure" better during e.g., home-assignments. Also get easily distracted by noise in the room (all excuses for substandard performance)." Jenny, one of participants wearing glasses, suggested that one should pay attention to the light conditions since she did not see the stimuli well and this could impact the data quality. Alberto recalled that "During this part of the study, I found it slightly hard to hear what was being said, and this could either be due to the recording, or simply to the fact that there was a good deal of ambient noise in the room while I participated in the study." Christine confirmed that "the room was noisy so of course there were parts of the video that I couldn't get to hear."

She also provided several comments succinctly summarizing the participants' experiences. "PROS: I like that it is a concise and short video. Attention drops fast. I also like the way the message was delivered (it was straightforward with good pauses between different sets of sentences). That helps to maintain focus. CONS: BEFORE watching the video, I got confused with some terminology used in the pre-test questions (to be more specific: "is it a function: $x$ to $y$ ?"). Watching the video clarified that."

Since in the second study participants were invited to answer the questionnaire, we organize their feedback in accordance with the questions.

*Q1 What video did you like the best and what the least, and why?*
Nora liked the best video 5: "I like to see a video of the teacher talking and I also dislike plain text or PowerPoints. I am used to this kind of teaching from Covid, so maybe that is why I liked it [video 5]. I also have ADHD, so it is harder for me to focus is nothing is moving." For Karl, the best and the worst were videos 2 and 6, respectively. Johan responded that videos "were all helpful in diverse ways, but video 5 was the most helpful because at the end of the video multiple examples were given. I liked video 3 the least because it was pure theory which for me is hard to translate into concrete implementations." Alessandro responded: "I like the most video 2 because it had good speed, and I could focus on information better plus highlighting the important parts and drawing examples helped. The worst is video 6 because every piece of information took too long, and I could not focus.

*Q2 What videos were the most and the least engaging, and why?*
For Nora, the least engaging was video 3, "even though they were writing everything they said, I found it kind of boring" and the most engaging was video 5 because of the presence of the teacher and drawing on slides. For Karl, the least engaging was video 6 because "it was boring, writing by hand unnecessarily prolonged it" and the most engaging was video 2 because "it was going by quickly, but visualization was still provided." Johan "noticed that both videos where the lecturer's face was visible were more engaging. Video 5 was the most engaging due to the practical examples." Alessandro confirmed that the most engaging was video 2 the least engaging was video 6 as I described in the previous question."

*Q3 How did the videos impact your understanding of the topic?*
Nora: "Because I forgot my Linear Algebra knowledge, it helped me get back on track, but I'd need an example how to use the theory because I was still lost." Karl: "not much, the topic was already known to me." Johan "learned of a new thing – the standard matrix. But it was not necessary for the completion of the questions – I already knew how to do vector-matrix multiplication. I feel like I did not understand completely what the standard matrix does. I pretty much just learned an unfamiliar word. I would have required more time, alone, to completely understand it." Alessandro responded: "I understood a little bit. Could not understand everything because I got lost with some terms in English."

*Q4 Did you find any aspects of the videos particularly helpful or challenging?*
Nora: "helpful - drawing. It helped me realise what actually is transformation about. Nothing was really challenging." Johan recalled that "the mathematics notation of how the function "$T$" and the standard matrix "$A$" are related was challenging. The pictures in video 5 were quite helpful." For Alessandro "the most helpful was the practical part in the end and the most challenging was to understand it from the definition."

Q5 Do you have any suggestions on how the videos could be improved?
Nora: "draw more and maybe try to use some real examples. I knew what was happening in theory, but I did not know how to answer correctly." Johan: "I would encourage the students, when showing the theory, to pause the video and read it at their own pace. I would also show examples of matrix-vector multiplication. I would also show examples of when the function is not a linear transformation. And then I would explain which of the two rules it violates." Alessandro "would prefer more practical parts."

Summarising students' feedback we can conclude that students
- value the presence of the lecturer in videos and engage better when they see even a small window with the presenter's face
- prefer dynamic assisted learning – they liked the best videos where the lecturer used prepared slides with mathematical text and presented it commenting, highlighting and illustrating details in the margins of the slides
- believe that the writing of mathematics text is boring and takes too much time
- have certain difficulties following theoretical material and value examples
- would like to see more applied problems and examples with explanations relating theory to practice

**Redesign**

In the forthcoming work, we plan to make several adjustments to our design:
- guidelines for participants will be prepared collecting all necessary information about the study and a Questions and Answers section were many questions asked during the experiments are answered
- since perception of videos is different for participants, in the next step we will try to adjust new videos to students' suggestions
- new formats of dynamic presentation should be tested
- it would be interesting to modify "boring" videos including some dynamic elements praised by students creating new hybrid formats

**Challenges**

There were several challenges that should be mentioned here:

- organisation of experiments requires certain efforts since all data are collected individually and this requires collective effort of the team and students adjusted outside classes
- iMotions software generates large amount of data which can be analysed in much more detail for answering quite specific research questions, but in the case of video materials this requires long hours of thorough work with the support of consultants at iMotions office
- educational research suggests that students remain focused on videos for about six minutes on average, and we have not arrived yet at the optimal balance between what lecturer should and wants to present in a video and what would students like to see there
- students have different learning preferences and learning styles which should be preferable considered, but it is very demanding to make several videos in vastly different formats for each topic.

**Conclusions**

Ideally, the best education should be tailored to each individual with the learning trajectory through university curriculum adjusted individually every semester, perhaps even more frequently. This adjustment implies the use of individualized study materials and personalized advice on the organisation of learning. The quality of the learning materials is of primary importance and requires continuous attention of educators and study administration. In this case study we explored the impact of short educational videos on students' learning.

The most important conclusions from this study are the following:

1) videos should be relatively short, up to 6 minutes, but informative, preferably with theory quite generously illustrated with examples
2) videos should be dynamic with the presenter highlighting on the slides, underscoring important text, and exemplifying the material in the margins
3) theoretical material should be presented at a right pace leaving students' some time for reflection
4) instructor's face should be visible in videos, even only in a small window – this contributes to students' better engagement, more trust in the material being presented, and helps to remove physical distance between the presenter and students by creating presenter's social presence and human contact in videos
5) students' feedback on video materials is immensely helpful for their redesign and improvement.

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