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Educational reconstruction to design and implement a video on climate change

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Physics topics such as climate change and the greenhouse effect are quite complex natural phenomena that are conceptually difficult for students to understand. It is important to develop instructional settings that aside from the scientific content, students' previous required knowledge and possible difficulties are also considered. Following the Model of Educational Reconstruction (MER) for the educational reconstruction of the scientific content and extending the Methodology for Video Development (MVD) to include feedback on the media characteristics, we created an educational video. The purpose of this design based research study was to better understand and build from high-school students' perceptions of the greenhouse effect as well as to strengthen the overall picture that the research community has of the possible learning outcomes when it comes to climate change. For this reason, the evaluation of the instrument that conveys the reconstructed material is considered important, as the Post-Test contains an extra part for the technical aspects of the video. The results are indicative of the video's effectiveness, as the core of the proposed educational reconstruction, led the students, although at different levels, to the integration of the new scientific knowledge, based on the personal revision of pre-instructional conceptions and therefore, to the refutation of most observed misconceptions.

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1. Introduction

In the last 10 years the EU has being recommending a set of innovative reforms for science teaching, incorporating environmental issues in the scientific curriculum, answering the need for making school a place of civic education. Currently, there is little emphasis within the science curriculum on discussion or analysis of environmental issues [1]. However, environmental issues have become an essential component of school curricula. Integrating environmental issues into the science classroom is one way to increase students' knowledge and improve students' attitudes and behaviors toward climate change [2, 3]. Education can enhance learners' capacities to understand climate change and encourage participation [4, 5].

Environmental issues, such as climate change, have proved to be an engaging context for motivating students, as several scholars suggest their integration to the school curricula. According to Thacker and Sinatra [6], climate change is conceptually challenging for students because it involves physical mechanisms that cannot be seen with the naked eye, occurs over extended periods of time and requires the ability to consider the complicated nature of interacting systems. Reasoning abstractly about systems that emerge from complex interactions of individual elements is challenging for students since they have relatively few experiences or mental representations that they can clearly associate with those complex interactions [6]. The crucial physics concepts involved in understanding the greenhouse effect (i.e. absorption, transparency, black body) are usually treated superficially, both from textbooks and from teachers [7]. Still, the traditional organization of scientific content in theories (i.e. thermodynamics, optics) is said to create barriers in understanding the greenhouse effect which is a typically intra-disciplinary issue [8].

Although the subject of climate change is one of the most important social scientific issues, numerous studies have shown that students' ideas and models about climate change are still inappropriate. According to the literature review of Thacker and Sinatra [6], students often conflate weather and climate since they call upon their daily experiences of weather as counter evidence to the more long-term effects of climate change. In addition, they often incorrectly assume that visible phenomena, such as smog or pollution, are responsible for the climate change, when in fact, many of the central mechanisms involved in the greenhouse effect are not visible to the human eye. Students also tend to conflate the greenhouse effect with stratospheric ozone depletion, believing that holes in the ozone layer are linked to climate change, a misconception that can persist even after direct instruction. In addition to these conceptual challenges and misconceptions, students' prior knowledge and attitudes can potentially interfere with their learning of science topics [9].

One way to enhance students' understanding of complicated natural phenomena is through visualizations. An example of teaching with visualizations is the use of educational videos. Visualizations generally provide students with more information and involve higher levels of interactivity than instruction presented in text or lecture format [10]. Therefore, educational videos must be carefully designed in order for them to be effective tools for integrating environmental issues into the science classroom. Although this study focuses on the scientific concept of climate change and greenhouse effect, the purpose of this work is also to bear broader implications for research on instructional design surrounding video-based learning. The extended MVD methodology followed is considered to be effective, and can be applied to other contemporary issues. Combined with the MER model, the educational reconstruction is based on the exposure to novel information that leads students to become dissatisfied with their prior conceptions and shift them to align understanding with scientific ideas, while respecting the norms of the medium i.e. the video. The following research questions are set:

1. Which are the most important misconceptions that can be addressed through the MER model about climate change and greenhouse effect?
2. Which are the main physics concepts about climate change and greenhouse effect that are needed to build the educational reconstruction?
3. How effective the prepared video is in leading the students to adopt the scientifically correct view of climate change?

2. Theoretical Background

2.1 Model of Educational Reconstruction (MER)

The Model of Educational Reconstruction (MER) [11] has been developed as a theoretical framework for studies investigating whether it is worthwhile and possible to teach particular science concepts, principles and views of the nature of science [12]. According to MER, the scientific content structure of a subject should be transformed into an educational one, which is suitable for students. This is achieved by studying and reconstructing the scientific content, after considering students' difficulties/ideas.

The model is based on a constructivist epistemological position of teaching and learning [13] and consists of three closely interrelated components: (a) Clarification and analysis of the science content, including analytical research on subject matter clarification and analysis of the educational significance of a particular science content. (b) Research on teaching and learning, comprising investigations of students' perspectives and their development towards the scientific view as well as studies on teachers' views and beliefs of the science concepts, students' learning and their role in initiating and supporting learning processes. (c) Design and evaluation of teaching and learning environments, comprising the design of instructional materials, learning activities, and teaching and learning sequences. The MER has been designed primarily as a frame for science education research and development. However, it also provides significant guidance for planning science instruction in school practice [12].

2.2 Methodology for Video Development (MVD)

The Methodology for educational Video Development, or MVD for short, works based on an initial content input for which the design of the educational video is required [14]. The original content may include text as well as photos. The MVD is based on the learning objectives set by the teacher to guide the development of the educational video. The original content should be divided into several sections where each has a separate purpose for the set goals. The purpose of MVD is to reduce the difference between the original content and the final video [14]. However, the present work is not a mere repetition of previous work on a different subject. The method is extended by including an extra step which is the evaluation of the technical aspects of the video. Such feedback is important to fulfill the criteria that the resulted video, apart from the careful design of the content, must also meet the aesthetic of the medium. We call it the extended MVD method (EMVD) and the six stages are the following: (1) Determination of the general learning objectives, (2) Determination of specific learning objectives, (3) Video construction, (4) Evaluation of the educational content, (5) Evaluation of the video characteristics and (6) Reformation.

3. Materials & Methods

The purpose of this work is the educational reconstruction of the scientific content about climate change and greenhouse effect so that it can be used to design an educational video that aims to foster students' conceptual understanding of these natural phenomena and the effect of human activity. The educational reconstruction was based on the MER model. This study also investigates the functions of video as an educational tool and the proper use of multiple representations, in order to address students' misconceptions about climate change and the greenhouse effect. The design, development and evaluation of the video were implemented by following and extending the MVD methodology in order to include feedback on the media characteristics.

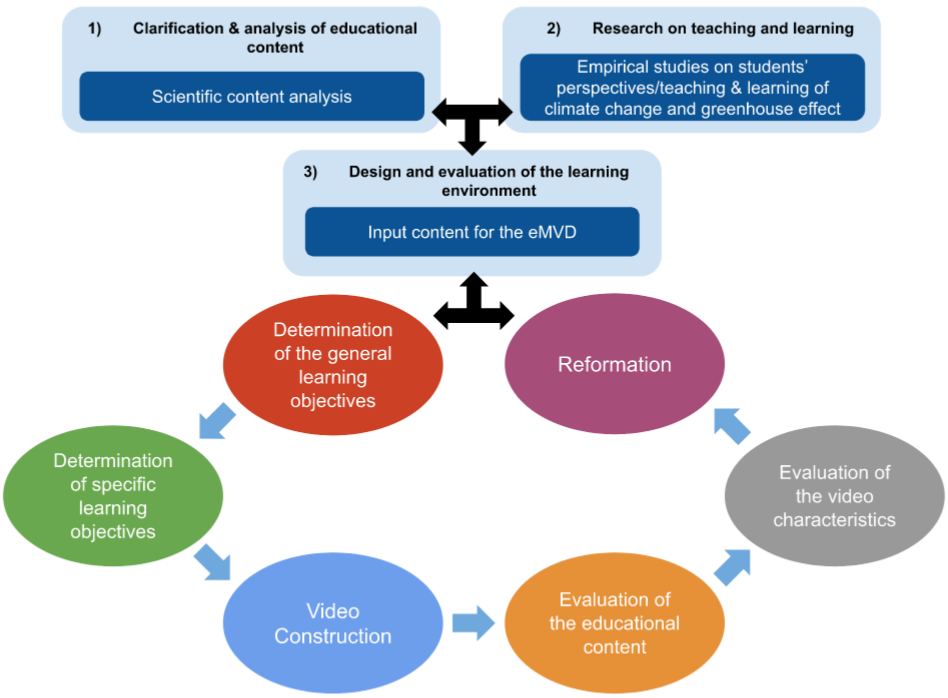

Figure 1: The combined methodology followed for the development of the educational video.

Figure 1 shows the combined methodology between MER and EMVD followed for the educational reconstruction of the input content and the development and evaluation of our educational video about climate change and greenhouse effect. Our research started with a parallel analysis of scientists' conceptions and students' conceptions as reported in literature and took the results of this for the development of teaching guidelines. The science content structure of the greenhouse effect found in university textbooks cannot be transferred directly into the content structure for instruction. It is necessary to take the students' prior conceptions into consideration within the learning discourse. This means that within the framework of the MER model, after the clarification of the scientific content on climate change and the greenhouse effect was done, and the central idea of the instruction was defined, in combination with the students' prior knowledge and the difficulties they have in understanding the phenomenon that have been identified in the research literature, the input content for the MVD was educationally reconstructed. Finally, the input content was filtered through the stages of the MVD to develop the educational video and through the results this process can be repeated as many times as needed to achieve the learning objectives set.

3.1 Scientific content

The term climate change refers to the change in the global climate and in particular to changes in conditions that extend over a large scale of time. Such changes include statistically significant fluctuations in the average state of the climate or its variability, extending over a period of decades or even more years. Climate change is due to natural processes, as well as human activities with an impact on the climate, such as changing the composition of the atmosphere.

According to Hausfather [15], the past million years of the Earth's history has been characterized by a series of ice ages broken up by relatively short periods of warmer temperatures. Ice-age cycles are primarily driven by periodic changes in the Earth's orbit. These distinct orbital cycles interact to change the distribution of incoming solar energy in ways that can dramatically affect the Earth's climate. These ice ages are associated with a large drop in global temperatures with much larger changes over land and in the high latitudes and are punctuated by inter-glacial periods where temperatures rise to around current levels. Changing atmospheric concentrations of carbon dioxide also plays a key role in driving both cooling during the onset of ice ages and warming at their end. If anthropogenic emissions continue to rise, it is almost certain that the world will warm more in just over a century than it warmed over many thousands of years during the end of the last ice age.

The atmosphere's role in the energy balance between the sun's radiation towards the ground and the radiation from the ground is very important; at the Earth's surface, the incoming solar radiation is transformed into outgoing radiation which is absorbed by the atmosphere, thus heating it. The atmosphere's protective role is now called the greenhouse effect. However, the radiative processes in the atmosphere are far more complicated. Contemporary climate models are incredibly powerful tools, not only for understanding the climate, but also for understanding the human contribution to global warming.

According to the MER model for elucidating and analyzing the scientific content, the central idea of this work must first be defined: **"The greenhouse effect is essential for the existence of life on Earth. It governs temperature because the greenhouse gases in the atmosphere – carbon dioxide, methane, water vapour and other gases – first absorb Sun's and Earth's infrared radiation and then release this absorbed energy, heating up the surrounding air and the ground below it"**. Figure 2 shows a simple energy balance model of incoming solar radiation. The thickness of the lines denotes the power that is transferred or reflected from Earth. Of the total amount of incoming radiation around 30% is reflected by clouds (20%), by particles in the atmosphere (6%) and by the Earth's surface (4%), while the other 70% is absorbed by ozone in the stratosphere (3%), by water vapour, clouds and aerosols in the troposphere (16%) and by the Earth's surface (51%). This energy is transferred to the atmosphere by heating the air in contact with the surface through the process of evapotranspiration and by long-wave radiation, which is absorbed by clouds and greenhouse gases. The atmosphere radiates heat energy back to the surface as well as to space. An illustrative and idealized calculation to quantify the greenhouse effect is:

$$G = E - F \tag{1}$$

(1) defines the greenhouse effect [16]. E is the energy emitted by the surface, F is the energy which escapes to space and G the energy trapped in the atmosphere. Therefore, G is the difference between the surface emission and the total energy loss.

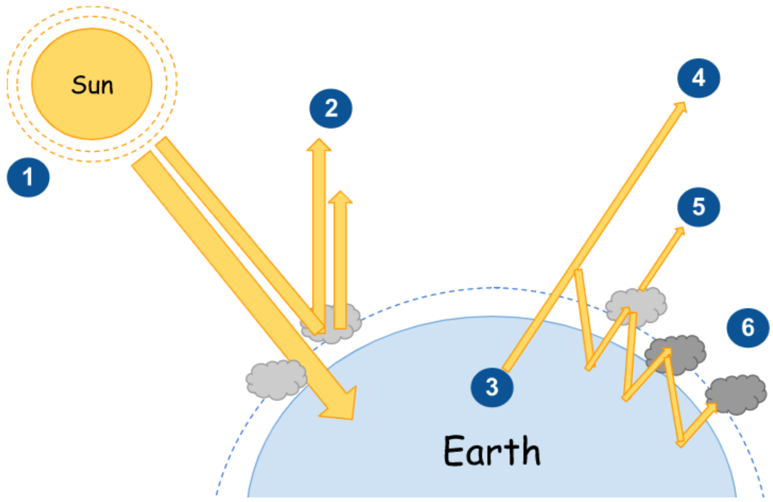

Figure 2: The greenhouse effect. (1) represents the total incoming solar radiation, (2) about half of it is reflected or absorbed by the clouds and the atmosphere, (3) is the remainder radiation absorbed by oceans and land percentage of which (4) heat is released towards space, (5) passes directly through the atmosphere, (6) but most of it is captured and retained by greenhouse gases.

Greenhouse gases actually comprise a very small proportion of the Earth's dry atmosphere, which is largely nitrogen and oxygen – 99% of the volume. Carbon dioxide is just 0.04% of the volume. The most powerful greenhouse gas is water vapour, but we cannot control the concentration of water vapour in the atmosphere, while we can control that of carbon dioxide. The amount of water vapour in the atmosphere is highly dependent on temperature, leading to a positive feedback mechanism. More carbon dioxide in the atmosphere makes the atmosphere warmer, allowing more water vapour to be held in the air, which increases the greenhouse effect and makes temperatures rise even further. If the carbon dioxide level drops, the temperature will fall and some water vapor will condense.

For a really strong greenhouse effect, Venus is a very good example. Venus is similar to Earth in terms of size and mass, but its surface temperature is about 460 degrees Celsius. The Venusian atmosphere is mainly made up of carbon dioxide, a greenhouse gas. On Earth, carbon dioxide makes up only a tiny fraction of the atmosphere. However, Venus is closer to the sun than Earth and receives far more sunlight. As a result, the planet's early ocean evaporated, water-vapor molecules were broken apart by ultraviolet radiation, and hydrogen escaped to space. With no water left on the surface, carbon dioxide built up in the atmosphere, leading to a so-called runaway greenhouse effect that created present conditions.

3.2 Students' perspectives on the topic

Before the design of the teaching material, the researcher must be aware of the students' ideas concerning the central topic. The design is lead by learning capabilities of the students on the one hand and clarification of science content on the other hand [11]. For this reason, some of the most common misconceptions about climate change and greenhouse effect are presented below according to literature and the research by McCuin et al. [17]. Specifically:

- The greenhouse effect is unnatural and dangerous.
- Greenhouse gases are a layer of pollution or dust that trap CO_2 underneath it (like a structure).
- The greenhouse effect does not depend on the human factor.
- There is nothing we can do about global warming.
- Wind and sunlight control climate much more than the oceans currents.
- Global warming causes ozone depletion.
- Increased levels of UV radiation coming into the Earth's atmosphere from ozone depletion heat up the Earth's surface.

To overcome conceptual obstacles about sunlight, radiation, or environmental issues (such as ozone depletion and the greenhouse effect), instructors should introduce ultraviolet radiation as a form of sunlight with special properties. They also need to include the conceptualization of the "sunlight" as a spectrum comprising different bands of radiation of different "character" and the notion that different atmospheric gases absorb electromagnetic radiation at different wavelengths.

According to Koulaidis and Christidou [18], to teach the greenhouse effect appropriately researchers should also focus on clarifying the conceptual distinction between solar and terrestrial radiation. This could be achieved by including that every body at a certain temperature emits electromagnetic radiation, that although much cooler than the Sun, the Earth itself emits long-wave infrared radiation and that different atmospheric gases absorb electromagnetic radiation at different wavelengths.

3.3 Educational Reconstruction

At this stage of the methodology, the design and the development of the educational video begins, as the reconstructed input content has been determined through the first two steps of the MER model.

3.3.1 Determination of general learning objectives

The main theme of this video is the greenhouse effect and climate change in general. The general learning goal we set for this reconstruction is for the student to demonstrate that the greenhouse effect is a natural process that protects our planet from the inhospitable conditions of space, as well as from the radiation of the Sun. It is deemed important to approach the phenomenon from the point of view of energy. It will also be pointed out that greenhouse gases are not responsible for the environmental impact, but their imbalance, which is created due to human activities.

One of the general objectives of this reconstruction is for the student to be able to describe the nature of radiation and how it affects the temperature of our planet, that is, to find that the above depends directly on how the radiation interacts with matter. It is also important to know about the composition of the Earth's atmosphere and which chemical elements and compounds help maintain the average temperature on the surface of our planet, and which are in excess. Finally, the student should be able to describe the main theme of this reconstruction, which is the greenhouse effect, as well as its effects on our daily lives.

By strictly defining the general objectives we set for our audience, it's important for the students to be able to (1) identify the factors that regulate the average temperature of the planet, (2) correlate color with the energy of visible radiation, (3) describe the process of interaction of the Sun's radiation with the Earth's atmosphere, (4) define the greenhouse effect and (5) indicate greenhouse gases and their properties.

Closing the first stage of the EMVD methodology we should choose the title of this educational reconstruction, as well as the keywords that will help us in its design. Therefore, according to what has been said on the subject and the learning objectives, the title of our educational video will be "Greenhouse gases: Friends or Enemies?". As for the keywords that we will highlight during the presentation will be: radiation, frequency, energy, interaction, temperature, atmosphere, chemical composition, climate, weather, greenhouse effect.

3.3.2 Determination of specific learning objectives

At this stage of the reconstruction, we define specific pieces of the theory which correspond to the set teaching goals and extract specific learning objectives. To facilitate this we divide the video into parts. By doing the same here, we define the specific goals for the target audience to be able to (1) separate the bands of the electromagnetic spectrum, (2) give examples of the use of radiation in science, (3) to classify greenhouse gases based on their contribution to the greenhouse phenomenon, (4) to link the excess of greenhouse gases with activities from everyday life and (5) list the positive and negative effects of the greenhouse effect. Closing with this stage of the educational reconstruction, the sections of the video will be connected with the specific objectives.

The introductory part should be linked to the fact that the Earth's climate is not a given, but depends on many factors. For this reason, the Earth's temperature is not constant, but it is a parameter that is constantly changing and it took millions of years for the creation and stability of our planet's atmosphere. The goal that corresponds to the second part of the video is the physical interpretation of radiation, the definition of energy quanta and the dependence of energy on the frequency of radiation, i.e Planck's Law. Finally, for a better understanding of the frequency dependence, the analysis of the radiation spectrum in parts is considered necessary. In the third

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part of the video the student should be able to know that radiation generally interacts with matter in three ways: absorption, reflection, emission. Also, some examples will be given regarding the effects of this interaction, depending on the energy/frequency of radiation. The learning objective of the last part is the greenhouse effect and greenhouse gases, how the phenomenon takes place, the consequences on our planet and how we can reduce them, as well as answer the key question posed by the video, "are greenhouse gases our friends?".

3.3.3 Video construction

At this stage, the design and construction of our educational video begins. Then, it was exported in video format (in Greek), while it was also uploaded to the YouTube video streaming platform. The video combines audio-visual elements (image and narration), while its duration is around 17 minutes. By dividing the video into parts, the educator is given the opportunity to integrate it in and augment parts of the curriculum.

3.3.4 Evaluation of the educational content

The evaluation of the video, now, includes the creation of a questionnaire given to 23 students from the three grades of an urban Lyceum in the field of Agriculture, Food and Environment. The survey was conducted in June 2021 and consisted of one questionnaire as Pre-Test and Post-Test with questions related to the subject matter of the video. The questionnaire (available upon request) was created through the Google Forms platform. It is based on existing surveys about MVD [14], but also in surveys conducted in the framework of the study of climate change [19]. Regarding the questions for the educational value as perceived by the students, are also based on existing surveys [20, 21].

The Pre-Test and Post-Test questionnaires were given to students before and after the video display. They have a part which is common and an additional one for the Post-Test regarding the new extra step of the video evaluation as media. The first part examines the contribution of the educationally reconstructed content of the video through questions related to its subject matter. They consist of 10 multiple choice questions with one or more answers.

Specifically, the first two questions are about climate change and correspond to the first part of the video and the learning objectives it covers. The next two questions examine the student's general knowledge of the concept of radiation associated with the second part of the video. The other six questions, which cover the last parts of the video and the main teaching objectives, deal with the greenhouse effect, greenhouse gases, the consequences of the phenomenon and the possible solutions to the climate change. The questions of the questionnaire do not cover all the points of the video, but only these deemed important for the student to assimilate. We must point out that during the processing of the Pre-Test, corrections were made to the reconstructed content, so that the presentation is in line with the evaluation. For this reason, we suggest that when designing an educational video, the evaluation of the educationally reconstructed content must be taken into account, so that there are no discrepancies between goals and outcomes.

3.3.5 Evaluation of the video characteristics

The additional questions of the Post-Test concern the evaluation of the video in terms of quality as a media in order to examine the satisfaction of the viewers. The Post-Test is augmented with

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questions on the characteristics and the educational value of the video as perceived by the students. The questions are given in the form of a scale (five-point Likert scale), where the student will be able to choose between 1 to 5 (minimum satisfactory to quite satisfactory). While the MVD method focuses on the learning objectives, we extend it and include the technical aspects of the video such as the duration, aesthetics etc.

In particular, this section consists of 14 questions. The first two are the demographics. By asking the gender and grade of the student, we will be able to check the percentage of participation between the two sexes and compare the results between the three grades of high-school. The next four questions examine the video in terms of the appropriateness (quantitative) of the elements that make it up (information, visuals, narration and duration). The next five questions concern the format of the video (qualitative), i.e its structure, scientific elements, visual elements and the rhythm of the narrative. Finally, the other three questions deal with perceptions of the students on matters like if it fosters the understanding of the subject, if the video promotes the interest in science and whether it could be included in the teaching of other school subjects.

3.3.6 Reformation

In the final step of EMVD, all the results are gathered and a quantitative and qualitative processing is carried out, in order to confirm the educational value of our video. By completing this final stage, the creator can recycle the process of the educational reconstruction of the initial content through the EMVD methodology until he reaches the desired outcome.

4. Results

In this section, a statistical analysis, through Excel and SPSS statistical package, of the questionnaire data is carried out. In this way, the advantages of the video that contributed positively to the fulfillment of the learning objectives were identified, as well as highlight the disadvantages. In order to process the collected data a per item-analysis that encompasses three measures was applied: item difficulty level, discrimination index, and point biserial coefficient [22]. Then, a normality test was conducted through SPSS, which indicated that the data were normally distributed.

4.1 Pre- and Post-Test analysis

A paired sample t-test was performed that compared the mean difference between the questionnaires. The outcomes of the analysis showed that students achieved cognitive progress that was statistically significant ($t(23) = 10.61$, $p < 0.001$). Specifically, each correct answer was assigned 1 point giving a maximum of 10 for the whole Pre-Test questionnaire. The average Pre-Test score for the whole questionnaire was 4.02 with a standard deviation of 1.41 (4.02 ± 1.41 (st.dev.)). After the video presentation, the average score of the Post-Test was 7.6 with a standard deviation of 1.41 (7.6 ± 1.41 (st.dev.)) (Table 1).

4.2 Satisfaction rates analysis

In this stage, the results of the Likert questionnaire given to the students after the video screening and the Pre-Test and Post-Test questionnaires are presented. These questions ask the students for

Table 1: Paired samples t-test results through SPSS analysis.

	Mean	N	Std. Deviation	Std. Error Mean
Pre-Test	4.0183	23	1.40923	0.29385
Post-Test	7.6017	23	1.40977	0.29396

some demographics to begin with and then their perception on the characteristics of the video in terms of its pedagogical value but also as a means of conveying information.

A normality test was conducted as in the previous part, which indicated that the data were normally distributed. Then, through the SPSS analysis, the following results were obtained (Table 2).

Table 2: Satisfaction rates means and std. deviations.

Questions	Mean	Std. Dev.
Appropriate amount of information	4.26	1.010
Appropriate use of visual elements	4.04	0.976
Appropriate use of narration	3.91	0.848
Appropriate video duration	3.96	1.186
Is the video well organized?	4.17	0.984
Did the included scientific data help you understand the content?	3.78	0.951
Where the visual features helpful?	3.70	1.146
Did you like the pace of the narration?	3.70	0.876
Does the video have a variety of features?	3.52	1.275
Did you understand the subject of the video?	3.91	1.083
Did the video helped you gain interest in science?	3.17	1.302
Could the video be used as an additional educational tool in the classroom?	3.96	0.976

The maximum score for each question is 5, therefore overall an average score close to 4 is achieved with the lowest being 3.17 and the highest for 4.26. We also examined whether the scores of the pre- and post-Test correlate with the Likert questionnaire. However, through a regression analysis carried out through the SPSS, it appeared that there is no direct correlation of the Pre- and Post-Tests with the results from the additional Likert questionnaire.

4.3 Comparison of results between the three grades

Here, another comparison was made through SPSS based on the the success rates of each high school grade for the Pre- and Post-Test (Fig. 3). The results show that these differences were significant between the Pre- and Post-Test of the same high school grade, but not between the three grades ($p > .05$).

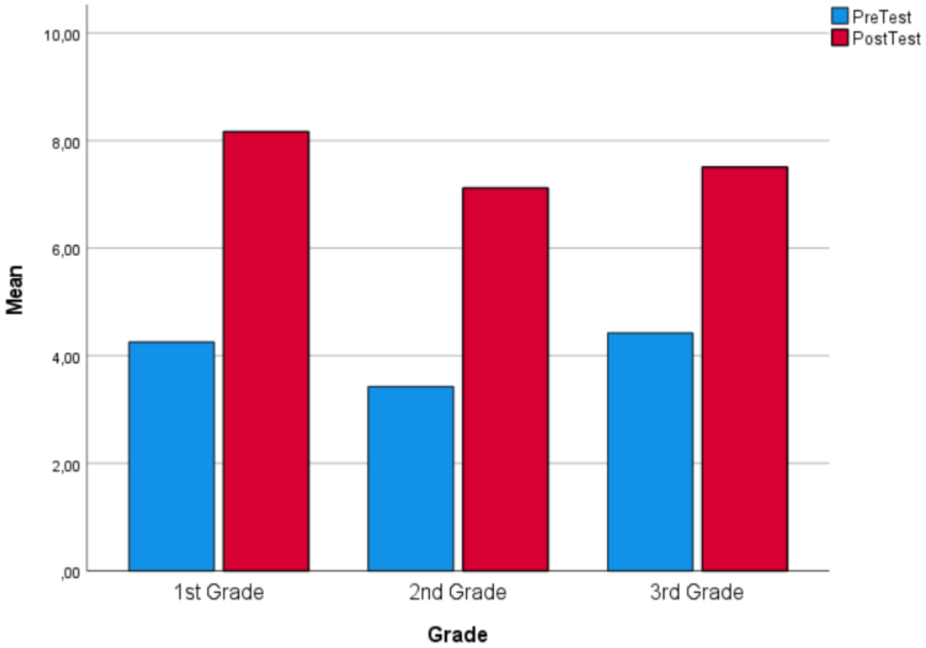

Figure 3: Mean difference of Pre- and Post-Test results at the three grades of High-School.

5. Discussion

Prior to the video viewing, students' knowledge consisted mainly of causes of global warming. They did not fully understand the scientific interactions and underlying principles that describe how the greenhouse effect and climate change occurs. This happens because the school curriculum does not take into account the prior knowledge and the difficulties that the students may encounter during the instruction. Therefore, according to the results of the Pre-Test, students do not seem to understand the unprocessed scientific content of the course. Specifically, many students showed several weaknesses in the questions concerning the nature of the greenhouse effect and the role of greenhouse gases. In particular, only 33% of students chose the correct answer in the question "What do you think is causing climate change?" before watching the video. As for the radiation, since their school curriculum does not focus on it, the percentages were justifiably unsatisfactory. For the definition of the greenhouse effect, 33% answered correctly. Therefore, it should be emphasized that the greenhouse effect is a vital and natural mechanism for maintaining the Earth's temperature. It is the human contribution to the environment that causes the problem by invoking the excess of greenhouse gases. Finally, as far the consequences of the greenhouse effect many students believed, before the intervention, that some of them are acid rain and the ozone hole. For all the above reasons, some changes were made to the reconstructed content in order to be more oriented towards these weaknesses observed in the Pre-Test before it was shown to the students.

After the video viewing, results indicate that students' understanding of the target phenomena was increased, but there is room for growth. The scientific content that students had been taught was now reconstructed according to the empirical studies on the specific subject according to the research literature and embedded as an input content in the form of an educational video. In order to develop a deeper understanding of the greenhouse effect and climate change, students had to learn about the individual components (solar energy, infrared energy, greenhouse gases, etc.), and understand the relationships between them. Regarding the nature of solar radiation, the answers after viewing the video were quite satisfactory. Many students developed an understanding of the relationship between greenhouse gases, infrared energy and the Earth's temperature. In terms of greenhouse gases and their sources, the success rates were satisfactory, as this piece was highlighted during the video. The question that had the lowest success rate compared to the Pre-Test was the question that examines the consequences of the phenomenon. Acid rain and the ozone hole were chosen again by the students, despite the fact that they were not even mentioned in the video. This means that some of the students wrongly associated this environmental problem with the reduction of the ozone layer, an idea already discussed in previous studies [23]. Their overall performance on these questions indicates that they are developing an integrated understanding of these phenomena.

The results of this research strengthen the overall picture that the research community has of students' handling of complex physics topics such as that of climate change and the greenhouse effect. Some changes need to be further made for the final video format in order to address the observed misconceptions that remained. The video creator can therefore, according to the new data gathered, repeat the process from the MER model to the MVD methodology in order to optimize his learning results. Some of the observed misconceptions have been identified and partially overturned by our intervention and also agree with the current literature in terms of climate change and the greenhouse effect:

1. Climate change is due only to the human factor or only to natural causes.
2. The carrier of electromagnetic radiation is the electron.
3. The electromagnetic spectrum consists of electromagnetic radiation.
4. The greenhouse effect does not depend on human activity
5. The ozone hole and acid rain are consequences of the greenhouse effect and climate change.
6. The effects of the greenhouse effect are due to the greenhouse gases.
7. The greenhouse effect alone is a harmful mechanism for life on the planet.

According to the analysis of the questionnaire on the technical aspects of the video, the results were generally satisfactory. The students perceived the included scientific information as sufficient. Combined with the evaluation for whether the video duration was appropriate, we conclude that the presentation may have tired the students, as the video duration exceeds the one that theory suggests (6-9 minutes). However, the students rated the other features of the video positively and seemed to understand its content as well. The students are also in favor to recommend our video as an educational tool. Therefore, these results show not only the effectiveness of our video as an instrument to convey the reconstructed material to the students, but also the importance of adding the extra step to the MVD methodology for feedback to the creator of the educational video.

By comparing the results between the three grades of high school, we conclude that the different grades had similar results. In addition, many misconceptions of the phenomenon have been identified in all three grades. This suggests, that the video is appropriate for the High-School grades with the condition that the unstructured scientific content will be reconstructed, considering all the prior required knowledge and difficulties of the students of this age range regarding the greenhouse effect and climate change.

6. Conclusions

In conclusion, the method used for explaining the greenhouse effect has epistemological and learning potentials which are progressively emphasised throughout the video. It is based on an energy balance reasoning and not on the wide-spread and misleading idea of "trapping", according to what is suggested by the most advanced studies. Students in secondary education struggle to understand the mechanisms behind climate change, specifically the greenhouse effect [6, 24]. However, grounding these abstract notions allowed participants to recall visual imagery in order to re-describe the mechanisms and causal rules that they had discovered while viewing the video.

The proposed methodology combines the MER model with the extended version of the MVD methodology in order to achieve a proper educational reconstruction to the initial scientific input content which will be used for the design and development of the video. The MER model provides a broadly conceived approach for subject-matter education research [11], while the EMVD increases the feedback not only on the cognitive part, but also on the characteristics of the media. That feedback is crucial in amending the initial design. As the limitations of the study, it must be made clear that it does not seek to generalize results to other cases due to the small sample size.

The educational video, as it turned out through the research we conducted and the combination of MER model and the EMVD method, is an effective teaching tool in the hands of the instructor. The teacher today has the ability, following specific methods and instructions, to easily create the educational material that will present the desired information to students through many representations. During this process, however, educator must pay special attention to the cognitive load but also to the characteristics of the medium, so that information will be presented methodically and purposefully.

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References

[1] J. Osborne and J. Dillon, *Science education in Europe: Critical reflections*, vol. 13, London: The Nuffield Foundation (2008).

[2] C.-H. Chang and L. Pascua, *Singapore students' misconceptions of climate change*, *International Research in Geographical and Environmental Education* **25** (2016) 84.

[3] J. Dewi, L. Hendarti, S. Matakupan and T. Lisdiyanta, *Suplemen pembelajaran perubahan iklim untuk guru (climate change learning supplements for teachers)*, *Jakarta: Kementeran Lingkungan Hidup* (2012) .

[4] J. Henderson, D. Long, P. Berger, C. Russell and A. Drewes, *Expanding the foundation: Climate change and opportunities for educational research*, *Educational Studies* **53** (2017) 412.

[5] A. Ocal, M. Kisoglu, A. Alas and H. Gurbuz, *Turkish prospective teachers' understanding and misunderstanding on global warming*, *International Research in Geographical and Environmental Education* **20** (2011) 215.

[6] I. Thacker and G.M. Sinatra, *Visualizing the greenhouse effect: Restructuring mental models of climate change through a guided online simulation*, *Education Sciences* **9** (2019) 14.

[7] G. Tasquier, F. Pongiglione and O. Levrini, *Climate change: an educational proposal integrating the physical and social sciences*, *Procedia-Social and Behavioral Sciences* **116** (2014) 820.

[8] U. Besson, A. De Ambrosis and P. Mascheretti, *Studying the physical basis of global warming: thermal effects of the interaction between radiation and matter and greenhouse effect*, *European Journal of Physics* **31** (2010) 375.

[9] D. Lombardi and G.M. Sinatra, *College students' perceptions about the plausibility of human-induced climate change*, *Research in Science Education* **42** (2012) 201.

[10] K. Varma and M.C. Linn, *Using interactive technology to support students' understanding of the greenhouse effect and global warming*, *Journal of Science Education and Technology* **21** (2012) 453.

[11] R. Duit, H. Gropengießer, U. Kattmann, M. Komorek and I. Parchmann, *The model of educational reconstruction–a framework for improving teaching and learning science*, in *Science education research and practice in Europe*, pp. 13–37, Brill (2012).

[12] D. Stavrou, E. Michailidi and G. Sgouros, *Development and dissemination of a teaching learning sequence on nanoscience and nanotechnology in a context of communities of learners*, *Chemistry Education Research and Practice* **19** (2018) 1065.

[13] R. Duit and D.F. Treagust, *Conceptual change: A powerful framework for improving science teaching and learning*, *International journal of science education* **25** (2003) 671.

[14] L. Moussiades, I. Kazanidis and A. Iliopoulou, *A framework for the development of educational video: An empirical approach*, *Innovations in Education and Teaching International* **56** (2019) 217.

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[15] Z. Hausfather, "Explainer: How the rise and fall of co2 levels influenced the ice ages." https://www.carbonbrief.org/explainer-how-the-rise-and-fall-of-co2-levels-influenced-the-ice-ages/, 2020.

[16] A. Berger and C. Tricot, *The greenhouse effect*, *Surveys in geophysics* **13** (1992) 523.

[17] J.L. McCuin, K. Hayhoe and D. Hayhoe, *Comparing the effects of traditional vs. misconceptions-based instruction on student understanding of the greenhouse effect*, *Journal of Geoscience Education* **62** (2014) 445.

[18] V. Koulaidis and V. Christidou, *Models of students' thinking concerning the greenhouse effect and teaching implications*, *Science Education* **83** (1999) 559.

[19] D. Dagkas and H. Polatoglou, *Digital educational material of the history of arrhenius' researches over the greenhouse effect*, *Re-introducing science Sculpting the image of science* (2019) 491.

[20] A. Mantha, N.L. Coggins, A. Mahadevan, R.N. Strehlow, M.C. Strehlow and S. Mahadevan, *Adaptive leadership curriculum for indian paramedic trainees*, *International Journal of Emergency Medicine* **9** (2016) 1.

[21] J.T. Nagy, *Evaluation of online video usage and learning satisfaction: An extension of the technology acceptance model*, *International Review of Research in Open and Distributed Learning* **19** (2018) .

[22] L. Ding and R. Beichner, *Approaches to data analysis of multiple-choice questions*, *Physical Review Special Topics-Physics Education Research* **5** (2009) 020103.

[23] B. Varela, V. Sesto and I. García-Rodeja, *An investigation of secondary students' mental models of climate change and the greenhouse effect*, *Research in Science Education* **50** (2020) 599.

[24] M.A. Ranney and D. Clark, *Climate change conceptual change: Scientific information can transform attitudes*, *Topics in cognitive science* **8** (2016) 49.

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