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Assessing Students' Ability to Apply the Control of Variables Strategy When Engaged with Inquiry-Based Worksheets during the COVID Era

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Abstract: In this study, an inquiry-based sequence was designed, developed and implemented using facets of flipped classroom and aspects of inquiry learning using the ADDIE model. The sequence intends to promote the students' scientific literacy. The aim of this paper is to examine the effectiveness of specially designed inquiry-based online worksheets (e-WS) to actively engage students in the design of unconfounded experiments by applying the Control of Variables Strategy (CVS). Second-year senior high school (11th grade) students participated in an intervention in which facets of flipped classroom approach with asynchronous and synchronous distance learning sessions were adopted, during the COVID-19 lockdown. Results show that the flipped classroom approach with synchronous and asynchronous sessions was acceptable and adoptable by the students; the existence of probe questions in e-WS, combined with explicit reference to inquiry procedure enhanced students' awareness of scientific practice and on CVS, while at the end of the intervention, students were capable of applying the CVS in the design of unconfounded experiments.

Keywords: distance learning; flipped classroom; inquiry-based worksheets; control of variables strategy

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1. Introduction

The spread of the COVID-19 pandemic has led to the reorganization of education at all levels around the world, including our country. On-site traditional (face-to-face) learning, due to these exceptional circumstances, has been replaced by distance learning. Remote distance education has been implemented all around the world, in two modes: asynchronous and synchronous [1,2]. Asynchronous distance learning is based on the interactions between the teacher and the learner at different times, while synchronous learning requires interactions in real-time, such as attending live online lectures [3]. The contribution of digital technology to the educational process and instructional design (either hardware or software), has become more than necessary in order to turn distance learning into effective online learning. Additionally, the lack of access to devices, broadband or even a quiet space to study for some students created a more challenging learning environment for both students and teachers [4]. However, lacking the traditional in-class practices, teachers had to put a greater effort into preparing online courses, innovating and designing lessons that would improve the attention span of the students [5]. Good practices are back, viewed from a different perspective, with the aim that students are not passive recipients of information, but active members of the learning process [6–9]. Several technology-driven models, such as the flipped classroom [10], have been adopted during the current pandemic, and authors have found that most students had a positive perception of this approach, noting the increased self-autonomy in learning with the advantage of practical online class activities [11].

From another point of view, the COVID-19 pandemic emergency showed, among other things, that the world's confidence in science seems to have been disturbed as unscientific views emerged gaining more and more supporters. Without scientific literacy, it is more difficult for citizens to make informed decisions on educational, scientific and, mainly, social issues that they may encounter in their everyday life. From this point of view, the design and implementation of didactic interventions aimed at developing scientific literacy skills are considered crucial as they will enable them to adapt more easily to the demands of their everyday life [12].

The spread of the COVID-19 pandemic led us not only to search for technologically appropriate strategies for distance education, but also to address the challenge of implementing didactic interventions that aim to develop scientific literacy skills. Teaching Physics does not only focus on the construction of conceptual knowledge but also the development of a scientific way of thinking, through the active involvement of the students in laboratory activities. Hodson proposed a holistic approach in which students are "doing science" that is much closer to scientific practice, using scientific methodology to investigate phenomena and solve problems [13,14]. In this line, several researchers argue that for effective teaching, laboratory practices, particularly inquiry-based activities, must be incorporated, to ensure active student participation [15,16].

In this paper, we have adopted facets of flipped classroom and aspects of inquiry learning, the first as a vehicle of the educational process and the second as a teaching–learning framework with cognitive, experimental and epistemological objectives, aiming to promote the students' scientific literacy. The hypothesis of the paper is that students' scientific literacy is promoted when students have developed inquiry skills, when they are engaged with inquiry-based worksheets in flipped classroom settings, during the COVID lockdown. Therefore, students are expected to be able to conduct their research and plan their experiments seeking evidence to the questions posed. In this paper, we are assessing the students' acceptance of the procedure adopted, and additionally their ability to apply the Control of Variables Strategy (CVS) in the design of unconfounded experiments.

1.1. Background

1.1.1. Flipped Classroom

The basic principle of the flipped classroom is that students are introduced to the content to be taught before coming to class through appropriate instructional material [17–19]. Therefore, the teaching time is used effectively for performing activities, which helps the students to clarify questions that may have arisen from the material they studied at home and thus to promote the new knowledge. In fact, if the teacher is aware of the involvement of students with the teaching material, it is possible for face-to-face teaching to be designed around the needs of students and to use the available time in the best possible way. Literature reveals that this approach can reduce the distance between the students and the targeted cognitive area in science courses. Very promising results seem to exist from its application in laboratory physics lessons, as it frees up time in the lesson to perform practical activities, instead of the classic lecture of the teacher, which leads to better performance and also improves the laboratory skills of students [20]. In addition, it was observed that this model helps to increase motivation [21] and helps students participate more actively in the lesson [22].

In our work, students had an asynchronous interaction with the instructional material (guided active engagement with a school textbook and properly designed digital worksheets with online simulations) before the synchronous online lesson [18,23] and acquired the new knowledge, which the teacher will discuss synchronously with them. Short questions of conceptual content aimed at learning difficulties and alternative conceptions are integrated into the worksheets. The aforementioned active engagement enhances students' motivation and encourages the learning process [24].

As the teacher is informed on time about the students' answers and their alternative ideas or difficulties, he adjusts his teaching properly [25]. In addition, the teacher leads the discussion in the class according to the students' answers, with students acquiring an active role in the lesson and not limited to passive attendance of a lecture. Therefore, in our work, we apply elements of the "flipped classroom" model, as the negotiation of new knowledge takes place before the lesson through the digital worksheets, which engage students in experimental work [17,18,25]. Specifically, conceptual questions are used, embedded among experimental activities, to inform the teacher about the level of knowledge that students have and to detect their alternative ideas. In addition, another element of this strategy is used, as the teacher adjusts his teaching and directs the class discussion based on the students' answers. So, a link between the course and the preparation is created, which contributes to the optimal use of available time, especially in emergencies such as the pandemic, where many of the lessons were from a distance due to the closure of schools.

Therefore, students asynchronously perform experimental activities, following guided worksheets and engaging with online simulations that help them understand the new theory, as well as clarify questions that may have arisen.

With the advancement of technology and the emergence of new multiparametric simulations, this model began to be used more and more in the field of science education, contributing to improving learners' ability to solve complicated problems [26].

1.1.2. Inquiry-Based Learning

Inquiry-based learning is one of the most promising tools for teachers to promote scientific literacy to their students since its main purpose is for learners to get involved in relevant activities and develop the ability to think and act in ways related to scientific inquiry [27]. The need for inquiry learning is based on the idea that science is a question-driven open process. In order for students to understand this aspect of science, they must engage in inquiry activities, which will provide them with valuable opportunities to deepen their understanding of both scientific content and corresponding scientific practices [28–30]. Although closely related to science processes, scientific inquiry extends beyond the mere development of process skills such as observing, inferring, classifying, predicting, measuring, questioning, interpreting and analyzing data. Scientific inquiry also refers to the combining of these processes with scientific knowledge, scientific reasoning and critical thinking to develop scientific knowledge [31].

Learning by inquiry is a teaching–learning approach where learners follow methods and practices similar to the scientific ones to construct knowledge [29]. Inquiry-based learning can be viewed as a set of skills to be learned by students and combined in the performance of a scientific investigation, as well as a cognitive outcome that students are to achieve. For example, it is one thing to have students set up a pre-defined well-controlled experiment, while it is another to expect students to understand the logical necessity for a well-controlled experimental design [31]. To achieve this, the teacher provides his students with scaffolded activities, which have a gradually decreasing support, from fully guided inquiry (where students follow instructions in a prescribed procedure), to open inquiry with a minimum of support, where students set up the whole investigation themselves [32]. Thus, the inquiry approach is considered as a continuum; at one end is the completely teacher-led process, while at the other end is the learner-led process, emphasizing the learner's active participation and responsibility to discover new knowledge [33].

Several authors have tried to classify inquiry from closed to open, depending on the amount of guidance provided. Bell et al. [34], assigned four levels (confirmation, structured, guided, open inquiry), based on three parameters, which gives the question, the methods, and the conclusion. Hegarty-Hazel [35] split the methods into "equipment" and "procedure" and the "guided inquiry" into two levels (guided-1 and guided-2). According to Du et al. [36], inquiry-based activities can be identified in six levels, ranging from Lecture/Demo (level 1) to Student-Designed Inquiry (level 6), depending on who is responsible (teacher/students) for specifying the topic, posing the questions to be investigated, or defining the experiment's setup, the methodology, or the method to be used for analyzing the results and drawing conclusions.

1.1.3. Control of Variables Strategy

By the term "Control of Variables" strategy (CVS), we mean the steps that one must follow in designing an experiment, so that by changing a particular variable, he/she can draw safe conclusions about the effect of that variable on the system under study [37]. Extensive research has been published on CVS. Readers may refer to a recent meta-analysis on the teaching of CVS, by Schwichow et al. [38].

In general, a variable can be related to the outcome of an experiment in three ways: (a) the variable can be unrelated to the outcome, (b) the variable can affect the outcome, in which case changing the variable can change the outcome or (c) the variable can determine the outcome, in which case that variable alone can be used to predict the outcome of the experiment. The way to manipulate the variables of an experiment depends on the relationship we want to test. To test whether a variable affects the outcome of a system, we need to recognize that the variable being tested must change from one trial to the next, while the other (independent) variables will remain constant [39].

The ability to design appropriate unconfounded experiments and draw valid conclusions from their results is one of the key skills in scientific thinking [37] and is required for the successful implementation of inquiry-based investigations. The CVS refers to the design and interpretation of an experiment, in which certain variables comparatively change value, with the aim of observing the effect of a variable on the behavior of a system [40]. The two processes, i.e., CVS and inquiry-based experimentation, are strongly interconnected. Apart from the fact that the CVS skills are required for the design of unconfounded experiments, Schalk et al, have recently reported the opposite, i.e., successful CVS application as a collateral benefit of inquiry-based physics education [41].

However, the implementation of CVS is a cognitively demanding process, both procedurally and conceptually, as it requires high logical thinking skills [37] as well as scientific argumentation [42]. Research shows that students of all ages find it difficult to acquire these skills and usually follow incorrect practices and unorthodox strategies of controlling the variables. Several methods have been proposed for teaching the CVS, from explicit to implicit (indirect) instruction, combined with various flavors of inquiry-based scaffolding. Zoupidis et al. [39] compared implicit to explicit method with guided inquiry and found that the latter has better results in improving CVS. It seems that the guidance provided is crucial for the improvement of students in this particular skill. Chen and Klahr [37] investigated the three possible combinations of guidance provided, with explicit teaching and probe questions. Their findings suggest that the combination of both explicit instruction and probe questions might be an effective approach to promote the mastery of CVS.

2. Materials and Methods

Due to the spread of the COVID-19 virus, a sequence of mixed synchronous and asynchronous teaching-learning sessions was developed, based on the "Flipped Classroom" scheme. Students were given material to study at home, in the form of simulation-driven inquiry-based worksheets. Five online worksheets (e-WS) were developed on the subject of electric circuits. The worksheets were developed using Google Forms and were accessible to students through the "e-class" of the Panhellenic school network. Following the "Flipped Classroom" scheme, students and the teacher thoroughly discuss the crucial points of the filled worksheets in the next synchronous session.

2.1. The Research Questions

RQ1: What is the students' participation in filling the e-WS?
RQ2: What are the students' views on the structure and guidance provided by the e-WS?
RQ3: How do students respond regarding the CVS to multi-variable experiments when the total number of the variables or the number of the dependent or independent variables changes and how it is developing through time?

2.2. The Sample

The inquiry-oriented intervention took place in the Experimental School of the University of Thessaloniki, during the academic year 2020–2021. The participants were 52 students, 26 boys and 26 girls, in the second year of senior high school (11th grade, 16–17 years old). The implementation was performed with synchronous (Webex environment) and asynchronous (e-class of the Panhellenic school network) activities. Students were familiar with the synchronous/asynchronous way of teaching from the previous year of global lockdown. Students had prior experience in performing cookbook experiments from previous years, however, without explicit orientation to the inquiry process or the CVS.

2.3. The Framework for the Development of the Online Worksheets

The inquiry-based sequence was designed and developed based on the ADDIE model, a framework used by many instructional designers and training developers to develop course content [43]. The name is the acronym for the five phases of the model, namely, Analysis, Design, Development, Implementation and Evaluation. In the Analysis phase, the instructional challenges due to the COVID-19 lockdown were established and the instructional goals and objectives set by the Curriculum were further clarified, taking into account the students' alternative conceptions and usually learning difficulties, to fit into the inquiry activities. In the Design phase, aspects of the inquiry-oriented teaching approach were set, creating web lab-based activities, from teacher-led to student-led processes, as the instructional framework, where the teacher scaffold experiences—from highly structured to more open—by varying the amount of guidance, enabling students to come up with self-conceived conclusions. Elements of the flipped classroom scheme were adopted also as the teaching method, where students actively and asynchronous participate in activities related to the content to be taught in the next synchronous lesson. The inquiry-oriented teaching approach allows students to construct their own knowledge by engaging in science [31]. Then, assessment instruments and lesson planning were set. In the Development phase, the content and strategies were integrated into the support tools chosen (Google Forms) as online e-worksheets. The role of the e-WS was twofold: (a) conceptual, i.e., to introduce the students to the cognitive content (electric circuits) and (b) procedural, i.e., to introduce the students to the nature and the phases of inquiry, aiming at fostering the development of students' scientific literacy. In the Implementation phase, the procedures for learners were developed, using online virtual simulators for building DC circuits. Finally, the Evaluation phase consists of tests for obtaining feedback and reviewing the developed e-WS. Data on students' participation (RQ1) were collected from the evolution of students' in competing with the e-WS. Data on the students' views (RQ2) were collected from recorded synchronous sessions. Data for assessing the students' mastery of the CVS (RQ3) were collected from the students' answers in e-WS and additionally by a post-test on students' ability to apply the CVS in the design of unconfounded experiments.

2.4. The Design and Development of the Teaching Materials

The e-WS designed for the needs of the intervention all follow exactly the same structure that involves the explicit stages of the inquiry. We have adopted the inquiry-based learning framework proposed by Pedaste et al. [44]. Pedaste et.al have synthesized an inquiry framework that combines the strengths of existing inquiry-based learning activities, through a systematic literature review of 32 papers that describe either the inquiry phases or the whole inquiry cycles. The Pedaste framework consists of five phases: orientation, conceptualization, investigation, conclusions and communication and reflection. The phases were then analyzed in steps of the inquiry process, and questions for each step according to Hackling [45]. The phases, steps and questions are outlined schematically in Table 1.

Table 1. Phases, steps and questions in the inquiry e-WS.

Phases of Inquiry		Steps of Inquiry	The Corresponding Question
5. Communication and reflection	1. Orientation	Statement of the problem	What is the problem to be solved?
	2. Conceptualization	Questioning	What are you going to investigate?
		Predicting	What do you think will happen? Explain why.
	3. Investigation	Designing the experiment	What equipment will you need?
			How will you control the variables? Which of the variables are you going to change, to measure or to keep constant?
		Executing the experiment	What happened? Record the data of the experiment.
		Performing data analysis and interpretation	Can your results be presented as a graph? Are there any relationships, patterns or trends in your results?
	4. Conclusions	Drawing conclusions	What did you find out about the problem you investigated?
		Comparing with initial ideas	Was the outcome different from your prediction?

The Orientation phase starts with a fictional story of everyday life. Johnny, the character of the story, is a young electrical trainee who wants to connect a lamp and a switch to an existing installation and wants to decide how to design the electric wiring for a house, wonders how Christmas lights are connected, etc., and students were asked to help him. Thus, students were provided with a meaningful problem worth investigating. They proceed by questioning, stating a prediction and giving the reason for it, planning and executing the experiment, performing data analysis and interpretation, drawing conclusions and comparing conclusions with their predictions. Reflection was practically invoked with summarizing questions in every inquiry phase, in the asynchronous sessions, when students were completing the e-WS at home. Communication in the fifth stage was performed at the end of the inquiry learning cycle, in the synchronous sessions, where students were discussing their ideas and findings with the teacher and their classmates. These stages/steps/questions of the inquiry process were explicitly presented in all the worksheets, in order to focus the students' attention and enhance their understanding of the inquiry procedure.

The five e-WS were designed for the needs of teaching the concepts of electrical circuits. Since the teaching was performed in lockdown conditions and students worked individually at home, the sequence of the e-WS followed the particular content-structure of the student's textbook, adopting elements of the flipped-classroom scheme. Each e-WS had two or three activities, each corresponding to one or two experiments to be performed by the students. The e-WS were developed following the inquiry continuum [45]. There is a gradual evolution of the inquiry from confirmation in the first worksheet, to structured and to guided inquiry in the last one. The sequence of the e-WS and the classification according to the inquiry continuum are outlined in Table 2.

Table 2. e-WS and Activities in terms of the content and the level of inquiry.

e-WS	Activity	Content	Level of Inquiry *
e-WS1	Act 1	Fundamental elements in a circuit	C
	Act 2	Electron movement in a circuit	C
	Act 3	The role of the electric source	S
e-WS2	Act 1	Bulb luminosity with respect to the voltage of the source	S
	Act 2	Current-ammeter connection	S
e-WS3	Act 1	Ohm's Law	S
e-WS4	Act 1	Bulb luminosity with respect to the number of the bulbs in series	S
	Act 2	The total resistance for bulbs in series	S
	Act 3	The role of the switch in a series circuit	S
e-WS5	Act 1	The role of the switch in a parallel circuit	G
	Act 2	Bulb luminosity with respect to the number of the bulbs in parallel	G
	Act 3	The total resistance for bulbs in parallel	G

* e-WS states online worksheets, C Confirmation, S Structured and G Guided.

In reference to Table 2, in the first two activities in e-WS1 the confirmation inquiry level is adopted, to introduce students to the stages of the inquiry and to familiarize them with the control of variables in the design of the experiment and with the whole philosophy of the worksheets. The sequence of the e-WS, activities, the experiments that students have carried-out and the variables were prompted to classify are presented in Table A1 in Appendix A. According to the structured inquiry level, students receive explicit step-by-step guidelines and follow the steps of a prescribed procedure, in the second, third, and fourth worksheets. The last worksheet was developed to follow the guided inquiry level and students had to decide how to collect the data of the experiment and take initiative in order to analyze and interpret them.

The e-WS were developed in Google Forms, which allows for the inclusion of pictures, combined with open- or closed-ended questions. Figure 1 shows snapshots of the e-WS. Our inquiry-based e-WS consist of texts, closed and open-ended questions, checklists and pictures. Similar to other tools for creating online interactive learning content (ex. Graasp [46]) Google Forms provides the possibility to extract the completed worksheets directly in Excel, an important feature for distance learning conditions.

The left snapshot of Figure 1 shows text on top, a picture of the circuit that students were asked to compose, multiple choice questions for their prediction and an open text for the justification of their prediction. The right snapshot shows the control of variables, where students are asked to mark on the check-boxes which of the variables are planning to change, to measure or keep constant. Next, in the two short-answer fields, students are asked to indicate the value of the current for two different batteries used.

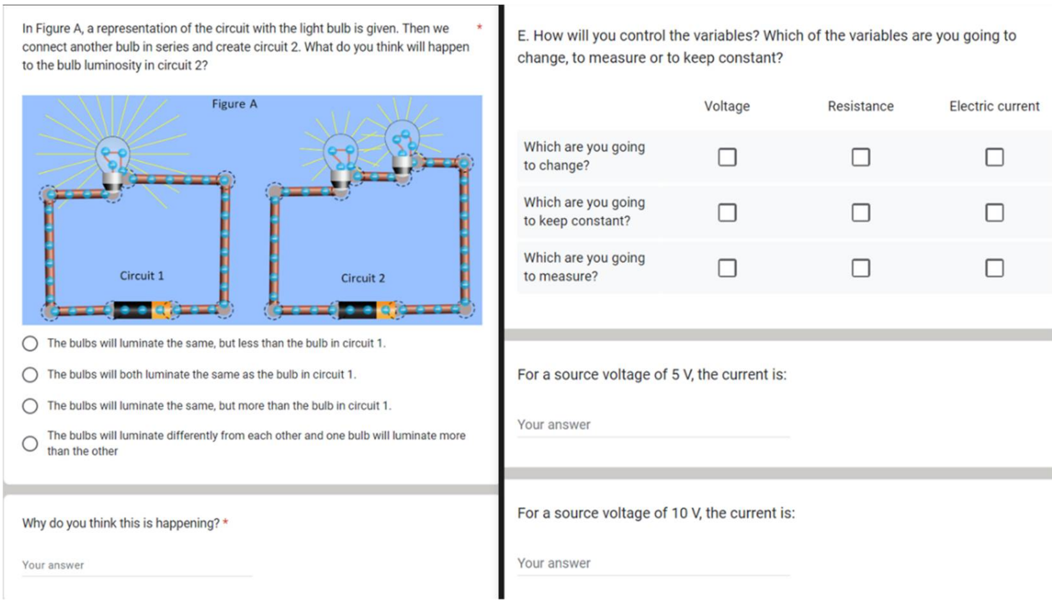

Figure 1. Characteristic snapshots of the e-WS.

A critical aspect of the e-WS, which is addressed in this paper, is the emphasis on the design of the experiments, and particularly on the control of variables. Students were asked in each e-WS to state which of the variables to change, which to measure and which to keep constant, i.e., to classify the variables as independent, dependent and control ones. Apart from the e-WS1, where students were explicitly introduced to the Control of Variables strategy, in the rest of WS, students had to manipulate either three or four variables, depending on the content requirements of each topic in the text-book. For example, they had to manipulate two dependent variables (ex. the bulb luminosity and the reading of the ammeter) or two independent variables in cases that two experiments were needed for the same activity, for example, whether the reading of the ammeter is affected by the voltage of the battery (experiment-1) and whether it is affected if the switch connected to a branch is open or closed (experiment-2).

Figure 2 portrays the intervention activities in a timeline. We can observe the sequence of activities, which require the handling of just three (orange) or more variables (blue) to be mixed in such a way as to provide scaffolding to students to handle more than three variables in the experimentation design. The first two activities in e-WS1 provide an explicit demonstration of the CVS in problems with four (Act1) or three (Act2) variables, to familiarize students with the strategy. In the following e-WS/Activities, probe questions were used, prompting students to determine "what they are going to measure/change/keep the same" for each experiment they had to deal with.

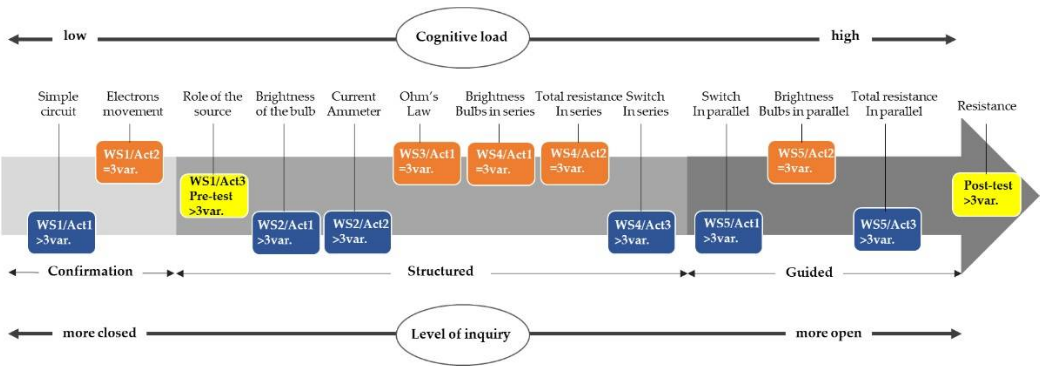

Figure 2. Timeline of the Worksheets.

The manipulation of more than three variables in e-WS1/Act3 is used as a diagnostic pre-test task to assess the students' ability to handle more than three variables. The last post-test was designed to check students' progress. The gradation of grey on the time arrow in Figure 2 corresponds to the level of inquiry: light, middle and dark grey refer to confirmation, structured, and guided inquiry, respectively. Figure 2 also shows the cognitive load of the worksheets with the flow of time. The sequence of e-WS gradually passes from simple to more complex problems. Thus, in the e-WS1 the students deal with the basic elements in a circuit with a battery, a switch and a bulb, they continue with examining the factors that affect the bulb luminosity (e-WS2) and proceed with the investigation of Ohm's Law (e-WS3). In the last two e-WS with higher cognitive load, the students treat with the connection of the bulbs in series and parallel.

2.5. Statistical Analysis

Nominal variables are reported as percentages and were compared through the χ^2 test. When a significant outcome was obtained, pairwise comparisons were performed through the same test with Bonferroni correction for multiple comparisons. Statistical analysis was performed using the SPSS, version 28 (SPSS, Chicago, IL, USA). Statistical significance was declared if $p < 0.05$.

3. Results–Discussion

3.1. The Implementation

The implementation, based on the online flipped classroom scheme, is schematically presented in Figure 3. The implementation scheme consists of three phases. According to the flipped classroom, in phase 1 students were given the material to study at home. Then, in the next phase, students were working with the Google-form e-WS, filling and submitting them as part of the asynchronous distance learning process. Students had a deadline to fill one e-worksheet per week (every Tuesday), which they discussed in class during the next teaching session, in synchronous mode with the Webex platform. In this phase, the teacher, having received the completed worksheets in time before the lesson, was able to adjust the teaching appropriately and guide the discussion effectively on topics where students were facing difficulties.

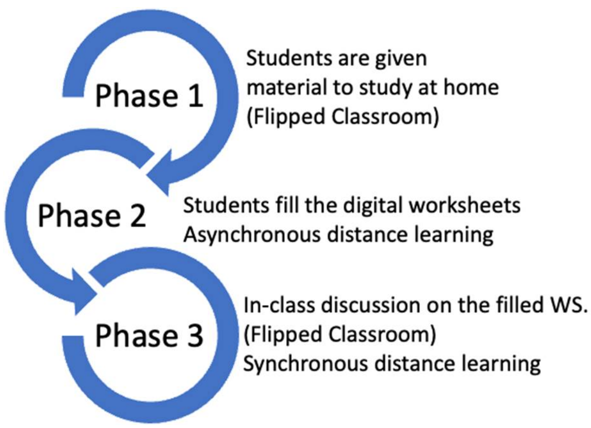

Figure 3. The implementation scheme.

Applying this scheme, students actively participated in the educational procedure, even in COVID-19 lockdown conditions, without requiring their physical presence at school. They were working at home with online virtual simulators for building DC circuits (https://phet.colorado.edu/en/simulations/circuit-construction-kit-dc-virtual-lab), and by following the steps and instructions given on the e-WS, they were introduced to the cognitive content and the stages of the inquiry. On the other hand, in the synchronous distance learning that followed, a discussion in the class based on the filled WS clarified issues, both conceptual and procedural, in which students faced difficulties.

The scheme of training within domains, combined with probe questions, has been proven effective for younger students in facilitating the acquisition of CVS [37]. In our implementation, with older students, we have adopted a hybrid model in which students followed an explicit demonstration of applying the CVS in e-WS1 and discussion in synchronous teaching on the difficulties that students were facing. Probe questions were asked in each activity to apply the CVS. Even though we didn't adapt the traditional teaching with transfer of knowledge about the CVS, the existence of probe questions in all the worksheets, combined with explicit reference to inquiry procedure seems to have enhanced students' awareness of CVS.

3.2. Evaluation of the Students' Participation

Figure 4 depicts the number of students in the class and the number of students who have completed the e-worksheets, as a function of time (worksheet number). As it is shown in Figure 4, though the completion of e-WS was not mandatory, the majority of students have participated in the inquiry-based intervention. Specifically, from a total of 52 students, 48, 41, 39, 39, and 35 students had completed the first, the second, the third, the fourth and the fifth worksheet, respectively. Almost 80% of the students have completed the four first e-worksheets. A small dropout of students' participation was observed in the last worksheet; however, a 62% percentage is still considered high for participation on a volunteer basis. This dropout might be due to the fact that this particular worksheet was much more demanding as it was composed in the form of "guided" in contrast to the "structured" inquiry form of the rest of the e-WS.

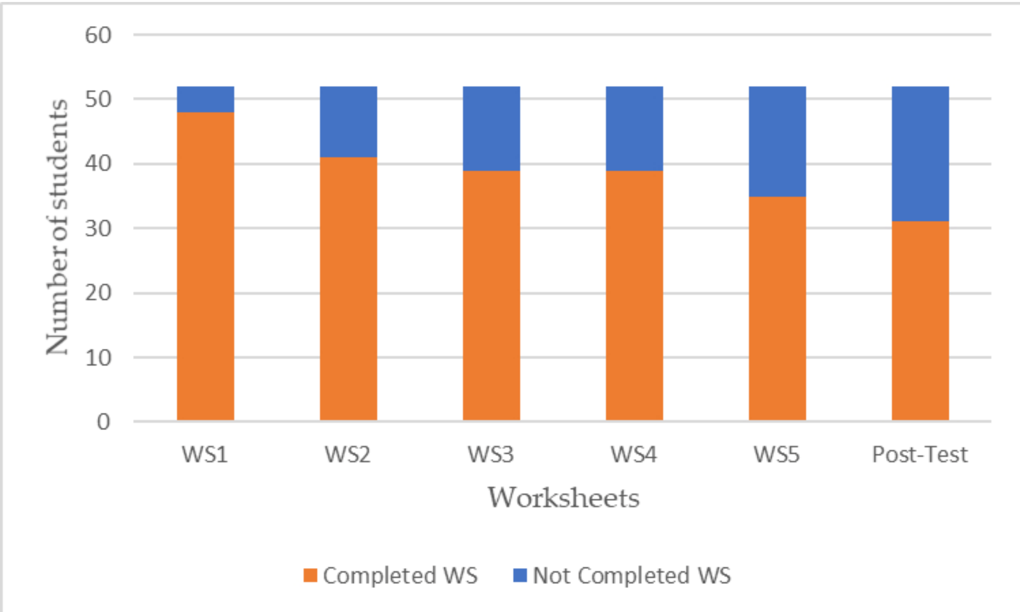

Figure 4. Students' participation in filling the e-worksheets.

3.3. Evaluation of the Control of Variables Strategy

Inquiry-based learning is often described as a sequence of steps, such as the formulation of a question to be investigated, investigation, generation of new thoughts and ideas based on the investigation analysis, discussion and reflection in connection with results. Even tough students in e-WS have completed the full cycle of inquiry-based learning, with planning-executing-evaluating experiments as a process in seeking for evidence. In this paper we will limit our discussion only to the students' applying the CVS in the design of experiments.

The design of an experiment plays a fundamental role in the inquiry procedure, and the Control of Variables Strategy (CVS) is an integral part of it. Students were given the problem to be investigated and were asked to classify the variables into independent, dependent and control.

Figure 5 shows the evolution of the correct answers with e-WS. If the color code is omitted, there is no clear trend as the number of correct answers keeps increasing and decreasing from one e-WS to the next and from one activity to the other. Color coding classifies the answers into pre-post-test (yellow), when students had to assign three variables into independent-dependent-control (orange) or four variables, where two of them were independent (blue) or two of them were dependent (grey). For the sake of clarity, we split the two cases (three or four variables) in Figure 5.

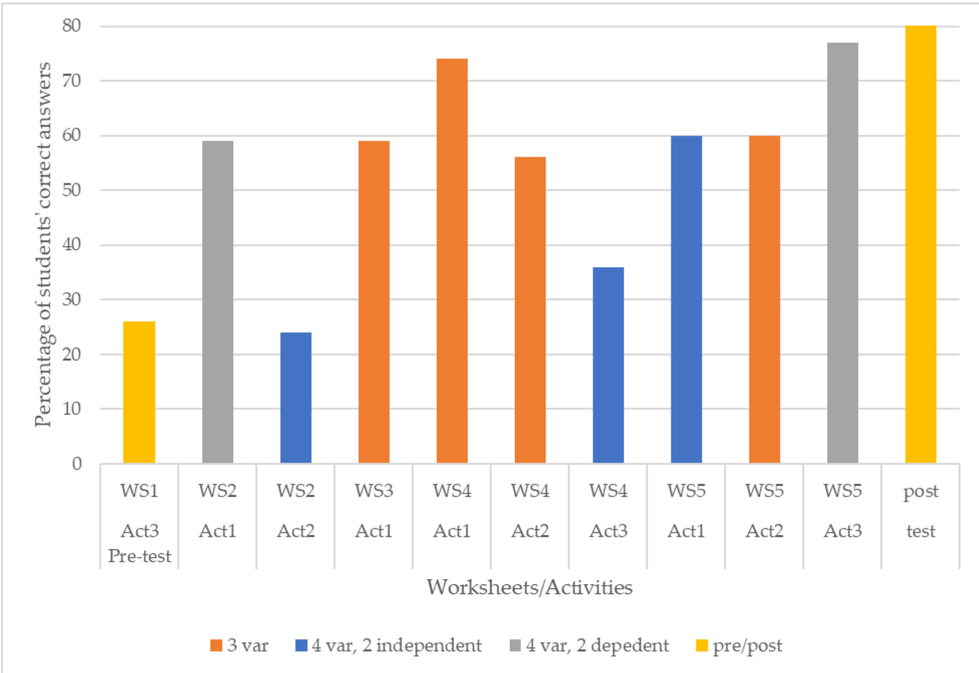

Figure 5. The evolution of the correct answers with e-WS.

Figure 6 shows the number of the correct answers of the students' classification of variables, relative to the number of variables that they were called to manage. The bars in orange represent the experiments that demand the control of only three variables, while the bars in blue or grey refer to the experiments with more than three variables. When students had to classify only three variables, one they measure (dependent), one they change (independent) and one they keep the same (control), the average score was high (>60%) even from the first worksheets and remains practically constant throughout the worksheets (Figure 6a, $p = 0.340$). Detailed statistical analysis can be found in Table A2 in Appendix B.

When comparing activities on the same topic, and therefore similar cognitive load, in activities with three variables, students perform better than with four variables (Act2 vs. Act3 in e-WS4). Therefore, students seem to face difficulties when they are asked to classify more than four variables (Figure 6b).

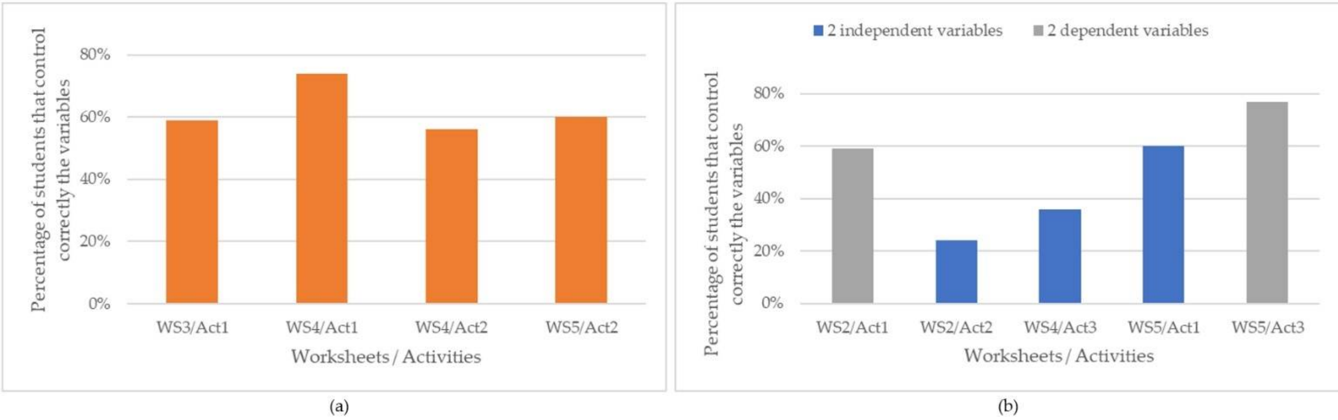

Figure 6. Control of variables in relation to the number of variables: (**a**) control of just three variables; (**b**) control of more than three variables.

The type of variables also seems to affect students' ability to classify the variables correctly. As shown in Figure 6b, the students' ability to apply the CVS in activities with two dependent variables (the ones that should be measured, bars in grey) did not differ significantly ($p = 0.141$, Table A3 in Appendix B). However, it was significantly better than in activities with two independent variables (the ones that should change, bars in blue). Specifically, e-WS2 had two activities, namely, activity 1 (Act1) where students had to deal with two dependent variables and activity 2 (Act2) where students had to deal with two independent variables. Though the topic was the same, and hence the cognitive load was similar, students were able to classify the variables correctly by 59% in Act1 while their correct answers were drastically decreased to 24% in Act2 ($p < 0.001$, Table A4 in Appendix B). Furthermore, the number of correct classifications in activities with two independent variables is increasing with time ($p = 0.004$, Table A5 in Appendix B). Comparing the first and the last activities with two independent variables, it is observed that the correct CVS in WS5/Act1 being significantly higher than in WS2/Act2 ($p = 0.001$), possibly due to students' familiarization with the structure of the e-worksheets.

The progress of the students to apply the CVS during the intervention is obvious since more students managed to classify the variables correctly, according to the problem stated. If we combine the data in Figure 2 with those of the blue bars in Figure 5, we can explain the improvement observed in the correct management of more than three variables in the last activities (blue bars). As it is seen, the three consecutive activities with the management of just three variables (WS3/Act1, WS4/Act1, WS4/Act2) "familiarized" students to also correctly handling activities requiring the control of more than three variables.

Figure 7 shows comparatively the % of the correct answers in the pre- (WS1/Act3) and post-test. Both in pre- and post-tests students were prompted to design an investigation in order to determine the role of the battery in a circuit (pre) and the factors which affect the resistance (post). In the post-test, students had not only to assign the variables but to justify their answer as well.

The pre-test (WS1/Act3) was given as structured inquiry, and therefore, both the variables and the experimental procedure to be followed were pre-determined in the e-WS. In the post-test students had to identify the variables themselves and design the experiment for each of the variables they had assigned as "independent", applying the CVS.

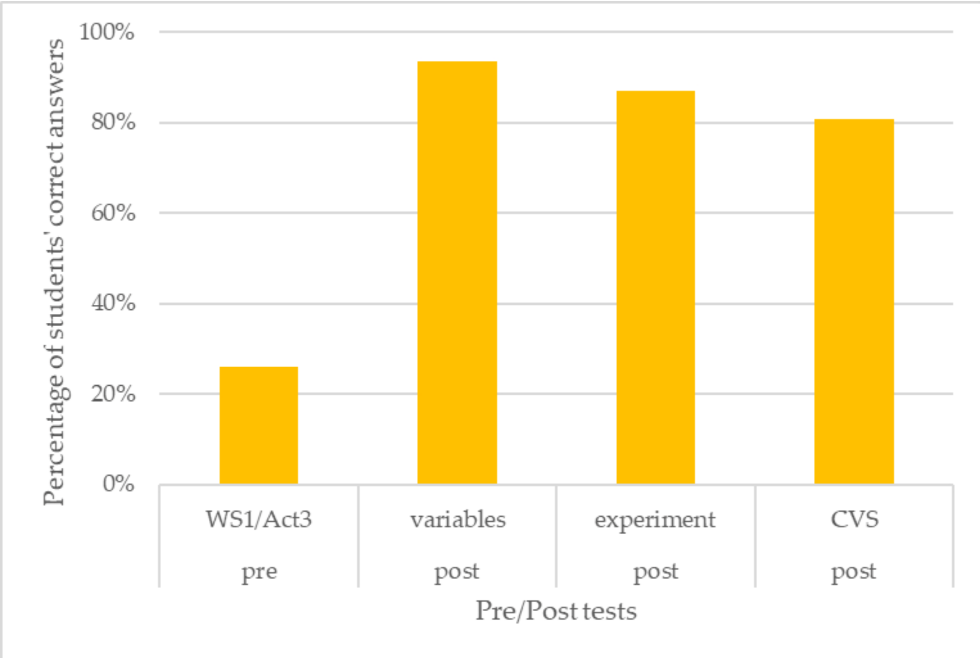

Figure 7. Students' performance in applying the CVS in the pre- and post-test.

The pre-test students' performance was significantly lower than the post one ($p < 0.001$, Table A6 in Appendix B), as only 26% of the students had managed to classify the variables correctly in the pre-test.

In all three aspects of the post-test (variables, experiment, and CVS) the percentage of correct answers was drastically higher, being 94%, 87%, and 81% respectively. This decline is expected, since it is conceptually easier to identify the factors which affect the resistance than to plan experiments in order to check the influence of each factor, and then to design the experiments unconfounded, applying the CVS. It is worth mentioning that 81% of the students, at the end of the intervention, were able to design unconfounded experiments for an open-ended problem.

The justifications of the students who answered correctly clearly state the independent and control variables, for example, planning a sequence of experiments and identifying the variables in each of them, for example "*firstly I change the material of the resistor while keeping the length, the cross-sectional area and the temperature the same, then I change the length while keeping the material, the temperature and the cross-sectional area the same. Then I change the cross-sectional area while holding the length, the material and the temperature constant and finally I change the temperature while holding the rest variables constant*" (student 14). In reference to the CVS justification, typical answers were "*In the first experiment I want to see how the change of the wire's length affects the resistance. So only this variable was changed, while all the other elements remained constant*" (student 15). The remaining 19% have not applied the CVS in full justification, without explicit reference to all the control variables ("*In order to investigate whether the length of the conductor is indeed a factor that determines the resistance, it is enough to compare conductors with the same cross-sectional area and different lengths*"), or focusing to the variable under investigation, thus, considering it to be the only variable which determines the outcome ("*increasing and decreasing the cross-sectional area of the conductor we observe the resistance changing inversely proportionally*").

Following the pre-post comparison and the students' justification analysis, we observe that at the end of the intervention more than 80% of the students were able to identify the variables correctly and apply the CVS in the design of experiments to check the effect of each of the independent variables they have identified.

3.4. Students' Views on the Process

Discussions between the teacher and the students during the synchronous meetings in Webex Classroom confirm the active participation of the students. The teacher mentioned that even students with limited participation in the Physics lessons had spent time working with the worksheets and participating in the discussions. Student's representative answers to the teacher's question about their impressions of their participation in the whole inquiry-based approach follow. Responses such as "*The fact that I knew what the lesson would be about, has helped me stay focused during my working at home alone*" or "*I did not expect to understand concepts on my own and perform experiments before the lesson*" show the effectiveness of flipped instruction. The majority of students referred to the explicit steps of the inquiry process in the worksheets: "*The fact that the steps of the inquiry were repeated in all the activities helped me to learn them*" or "*Although I found it tedious to repeat the steps of the inquiry it helped me learn the steps we are following*". It is worthwhile to mention that one student, whose interest and performance in the Physics lesson was weak, participated actively in the whole procedure and even suggested the completion of e-worksheets to be a way of summative assessment in the Physics lesson.

4. Conclusions

This study aimed at examining the effectiveness of specially designed inquiry-based e-WS to actively engage students, in scientific method and aspects of Control of Variable Strategy (CVS). The intervention was applied to students in their second year of senior high school. Following the ADDIE model, an inquiry-based sequence was designed, developed and implemented using facets of flipped classroom and aspects of inquiry learning, aiming to promote the students' scientific literacy during the COVID-19 era.

In reference to the first research question, on the students' participation, we have noticed that the majority of students actively participated and were engaged in the educational procedure. In the asynchronous mode of distance learning, most students expressed positive views on the process and almost 80% of the students filled the e-WS at home, following explicit instructions of the inquiry stages, planning their experiments, seeking evidence to the questions posed in the e-WS and drawing their conclusions. On the other hand, in the synchronous mode of distance learning, students aware of the subjects to be taught actively participated in the class discussion, clarifying issues that made it difficult for them. It seems that the students' engagement with the guided inquiry e-WS, before the synchronous lesson [22], contributed to overcoming the risk of non-participation in distance learning, mentioned in the literature [4,5,47].

Concerning the second research question, about the students' views on the structure and guidance provided by the e-WS, the results are encouraging. Even though we didn't adapt the explicit traditional teaching with transfer of knowledge about CVS, which seems to be effective for younger students [37], the existence of probe questions in all the worksheets combined with explicit reference of inquiry procedure enhanced students' awareness of scientific practice and on CVS. So, even students with limited participation in the Physics classes have spent time filling in the e-WS and also participated actively in the discussions during the synchronous lessons. Students mentioned the effectiveness of flipped instruction as they didn't expect to understand concepts on their own and to perform experiments before the lesson. The majority of students also referred to the explicit steps of the inquiry process in the e-WS in helping them to be aware of the inquiry procedure.

Regarding the third research question on the ability of students to apply the CVS in the design of unconfounded experiments, results show 60% or more correctly apply the strategy when they are asked to assign three variables (one independent, one dependent and one control). When they are asked to handle more than three variables, their score is in similar levels (~60% or more) when the problem requires two dependent variables. Though at first they seem to face difficulties in handling more than one independent variables (~25%), the number of correct classifications increases up to ~80% as students are engaged in the inquiry-based sequence and become more and more familiar with the structure of the e-WS. The design of a sequence with mixed activities which require the handling of just three or more variables provided scaffolding to students to assign correctly more than three variables in the experimentation design. It is worthwhile to mention that when the majority of the variables were the ones that should be measured (dependent) and not the ones that they should change (independent), the students show better results. At the post-test, the majority of students (more than 80%) were able to identify the variables correctly and to apply the CVS in the design of unconfounded experiments to check the effect of each of the independent variables they have identified and justify their options. This result is significantly higher that the best results reported by Chen and Klahr [36].

Concluding, it seems that the students' engagement in a sequence including facets of flipped classroom and aspects of inquiry learning, even in distance learning conditions, can help them to participate actively in the learning process and to be aware to apply the Control of Variables Strategy (CVS) in the design of unconfounded experiments. The aforementioned enhancement of students' awareness on scientific practice and on CVS is connected with the development and fostering of scientific literacy skills, which was also our aim, as was mentioned in the Introduction and recorded in the literature [47–50]. The outcomes of the present study suggest that crucial procedural knowledge in designing experiments, such as CVS, is possible to be taught to older students, even without explicit traditional teaching with the transfer of knowledge. Appropriate designed inquiry-based worksheets could have a wider application to lower secondary students in order to enhance their active participation in the learning process and promote fundamental aspects of experiment design.

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Appendix A

Students were gradually introduced from the fundamental elements in a circuit to advanced topics such as the connection in series and in parallel. Thus, in WS1, students study the effect of the source (battery) and the switch on the luminosity of a bulb, they examine the effect of temperature on the electron motion in the current conductors, and finally how the source and the switch affect the directional motion of the electrons. WS2 connects the electron velocity to the luminosity of the bulb, introduces the concept of electron flow and finally examines the connection of an Ammeter in a circuit. WS3 is the classical experimental treatment of the Ohm's Law. WS4 examines the connection of electronic elements in series, i.e., the luminosity of bulb, the current and the role of the switch. Finally, WS5 examines the bulb luminosity of bulbs, the current and the role of the switch in different branches in a parallel circuit. The sequence of the WS, activities, experiments per activity and the variables were prompted to classify, is presented in Table A1. In the main text.

Table A1. The sequence of the WS, activities, experiments per activity and the variables were prompted to classify.

WS/Act	Topic	Experiments	Variables *
WS1/Act1	Fundamental elements in a circuit	The effect of the battery on the bulb luminosity (exp.1)	Battery, Switch, Bulb resistance, Bulb luminosity
		The effect of the switch on the bulb luminosity (exp.2)	
WS1/Act2	Electron movement in a circuit	The effect of temperature on the electron motion (exp.1)	Temperature, Bulb resistance, electron motion
WS1/Act3	The role of the battery and the switch	The effect of the battery on the electron velocity (exp.1)	Battery, Switch, Bulb resistance, Electron velocity
		The effect of the switch on the electron velocity (exp.2)	
WS2/Act1	Bulb luminosity and speed of electron flow	Comparing bulb luminosity and electron velocity for various batteries (exp.1)	Batteries, Bulb resistance, Bulb luminosity, Electron velocity
WS2/Act2	Current ammeter connection and rate of flow of charge	The effect of the battery on the electron flow rate (exp.1)	Battery, Connection of the ammeter, Bulb resistance, Electron flow rate
		The effect of the ammeter's connection on its function (exp.2)	
WS3/Act1	Ohm's Law	The effect of the battery's voltage on the current (exp.1)	Battery, Current, Bulb resistance
WS4/Act1	Bulb luminosity of bulbs in series	The effect of the number of bulbs on bulb luminosity (exp.1)	Number of bulbs, Battery, Bulb luminosity
WS4/Act2	The current in a series circuit	The effect of the number of bulbs on the current (exp.1)	Number of bulbs, Battery, Current
WS4/Act3	The role of the switch in a series circuit	The effect of the number of the switches on the bulb luminosity (exp.1)	Number of switches, Number of Bulbs, Battery, Bulb luminosity
		The effect of the number of light bulbs in relation to the number of switches on the bulb luminosity (exp.2)	
WS5/Act1	The role of the switch in a parallel circuit	The effect of the number of the switches on the bulb luminosity (exp.1)	Number of switches, Number of Bulbs, Battery, Bulb luminosity
		The effect of the number of light bulbs in relation to the number of switches on the bulb luminosity (exp.2)	
WS5/Act2	Bulb luminosity in parallel	The effect of the number of bulbs on bulb luminosity (exp.1)	Number of bulbs, Battery, Bulb luminosity
WS5/Act3	The current in a parallel circuit	The effect of the number of bulbs on the current and bulb luminosity (exp.1)	Number of bulbs, Battery, Current, Bulb luminosity

* Though, the bulb resistance was kept unchanged in all experiments, students were prompted to take this variable into consideration in the classification of variables.

Appendix B

Statistical analysis on students' performance with the e-WS sequence, when they are asked to classify only 3 variables (data presented in Figure 6a).

Hypothesis: There is a statistically significant difference on students' performance with the e-WS sequence, when they are asked to classify only 3 variables.

Table A2. Students' performance with the e-WS sequence, with classification of only 3 variables.

Chi-Square Tests			
	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	3.353	3	0.340
Likelihood Ratio	3.482	3	0.323
Linear-by-Linear Association	0.265	1	0.606
N of Valid Cases	156		

In these results, the Pearson chi-square value is 3.353 and the corresponding p-value is 0.340. The likelihood chi-square value is 3.482 and the p-value is 0.323. Therefore, at a significance level of 0.05, we can conclude that there is not statistically significant difference on students' performance with the e-WS sequence.

Statistical analysis on students' performance with the e-WS sequence, when they are asked to classify 4 variables of which two are dependent (data presented in Figure 6b, bars in grey).

Hypothesis: There is a statistically significant difference on students' performance with the e-WS sequence, when they are asked to classify 4 variables of which two are dependent.

Table A3. Students' performance with the e-WS sequence, with classification of 2 depended variables.

Chi-Square Tests					
	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	2.167	1	0.141		
Continuity Correction	1.505	1	0.220		
Likelihood Ratio	2.184	1	0.139		
Fisher's Exact Test				0.220	0.110
Linear-by-Linear Association	2.139	1	0.144		
N of Valid Cases	78				

In these results, the Pearson chi-square value is 2.167 and the corresponding p-value is 0.141. The likelihood chi-square value is 2.184 and the p-value is 0.139. Therefore, at a significance level of 0.05, we can conclude that there is not statistically significant difference on students' performance with the e-WS sequence.

Statistical analysis on students' performance on the same topic, when they are asked to classify 4 variables of which 2 are dependent or independent (data presented in Figure 6b, Act1 vs. Act2 in e-WS2).

Hypothesis: There is a statistically significant difference on students' performance on the same topic, when they are asked to classify 4 variables of which 2 are dependent or independent.

In these results, the Pearson chi-square value is 11.818 and the corresponding p-value is < 0.001. The likelihood chi-square value is 12.172 and the p-value is < 0.001. Therefore, at a significance level of 0.05, we can conclude that there is statistically significant difference on students' performance with 2 dependent or independent variables on the same topic.

Statistical analysis on students' performance with the e-WS sequence, when they are asked to classify 4 variables of which two are independent (data presented in Figure 6b, bars in blue).

Table A4. Students' performance on the same topic with classification of 2 depended or independent variables.

Chi-Square Tests					
	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	11.818	1	<0.001		
Continuity Correction	10.295	1	0.001		
Likelihood Ratio	12.172	1	<0.001		
Fisher's Exact Test				0.001	<0.001
Linear-by-Linear Association	11.667	1	<0.001		
N of Valid Cases	78				

Hypothesis: There is a statistically significant difference on students' performance with the e-WS sequence, when they are asked to classify 4 variables of which two are independent.

Table A5. Students' performance with the e-WS sequence with classification of 2 independent variables.

Chi-Square Tests			
	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	10.819	2	0.004
Likelihood Ratio	10.955	2	0.004
Linear-by-Linear Association	10.442	1	0.001
N of Valid Cases	117		

In these results, the Pearson chi-square value is 10.819 and the corresponding p-value is 0.004. The likelihood chi-square value is 10.955 and the p-value is 0.004. Pairwise comparison between WS5 and WS2 is 0.001 with Bonferroni correction 0.017. Therefore, at a significance level of 0.05, we can conclude that there is statistically significant difference on students' performance with the e-WS sequence.

Statistical analysis on students' performance with pre and post-tests (data presented in Figure 7).

Hypothesis: There is a statistically significant difference on students' performance with the pre and post-tests.

Table A6. Students' performance with the pre and post-tests.

Chi-Square Tests			
	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	44.385	3	<0.001
Likelihood Ratio	43.039	3	<0.001
Linear-by-Linear Association	18.961	1	<0.001
N of Valid Cases	124		

In these results, the Pearson chi-square value is 44.385 and the corresponding p-value is < 0.001. The likelihood chi-square value is 43.039 and the p-value is < 0.001. Therefore, at a significance level of 0.05, we can conclude that there is statistically significant difference on students' performance with the pre and post-tests.

References

1. Dhawan, S. Online Learning: A Panacea in the Time of COVID-19 Crisis. *J. Educ. Technol. Syst.* **2020**, *49*, 5–22. [CrossRef]
2. Nasrullah Role of Multimedia Tutorials in Distance Education. *Int. J. Infonomics* **2014**, *7*, 933–941. [CrossRef]
3. Shahabadi, M.M.; Uplane, M. Synchronous and Asynchronous E-Learning Styles and Academic Performance of e-Learners. *Procedia Soc. Behav. Sci.* **2015**, *176*, 129–138. [CrossRef]
4. Sofianidis, A.; Meletiou-Mavrotheris, M.; Konstantinou, P.; Stylianidou, N.; Katzis, K. Let Students Talk about Emergency Remote Teaching Experience: Secondary Students' Perceptions on Their Experience during the COVID-19 Pandemic. *Educ. Sci.* **2021**, *11*, 268. [CrossRef]
5. Sun, L.; Tang, Y.; Zuo, W. Coronavirus Pushes Education Online. *Nat. Mater.* **2020**, *19*, 687. [CrossRef]
6. Beason-Abmayr, B.; Caprette, D.R.; Gopalan, C. Flipped Teaching Eased the Transition from Face-to-Face Teaching to Online Instruction during the COVID-19 Pandemic. *Adv. Physiol. Educ.* **2021**, *45*, 384–389. [CrossRef] [PubMed]
7. Clark, R.M.; Kaw, A.K.; Lou, Y.; Scott, A.R. The Flipped Classroom during the Remote Period of COVID: Student Perceptions Compared to Pre-COVID Times. *Int. J. Math. Educ. Sci. Technol.* **2022**. [CrossRef]
8. Ma, W.; Luo, Q. Pedagogical Practice and Students' Perceptions of Fully Online Flipped Instruction during COVID-19. *Oxford Rev. Educ.* **2022**, *48*, 400–420. [CrossRef]
9. Tang, T.; Abuhmaid, A.M.; Olaimat, M.; Oudat, D.M.; Aldhaeebi, M.; Bamanger, E. Efficiency of Flipped Classroom with Online-Based Teaching under COVID-19. *Interact. Learn. Environ.* **2020**. [CrossRef]
10. Gopalan, C.; Butts-Wilmsmeyer, C.; Moran, V. Virtual Flipped Teaching during the COVID-19 Pandemic. *Adv. Physiol. Educ.* **2021**, *45*, 670–678. [CrossRef]
11. Campillo-Ferrer, J.M.; Miralles-Martínez, P. Effectiveness of the Flipped Classroom Model on Students' Self-Reported Motivation and Learning during the COVID-19 Pandemic. *Humanit. Soc. Sci. Commun.* **2021**, *8*, 176. [CrossRef]
12. Glynn, S.M.; Muth, K.D. Reading and Writing to Learn Science: Achieving Scientific Literacy. *J. Res. Sci. Teach.* **1994**, *31*, 1057–1073. [CrossRef]
13. Hodson, D. Assessment of Practical Work. *Sci. Educ.* **1992**, *1*, 115–144. [CrossRef]
14. Johnstone, A.H.; Al-Shuaili, A. Learning in the laboratory; some thoughts from the literature. *U. Chem. Ed.* **2001**, *5*, 42–51. Available online: https://rsc.li/2YMlKb2 (accessed on 5 May 2022).
15. Garnett, P.J.; Garnett, P.J.; Hackling, M.W. Students' Alternative Conceptions in Chemistry: A Review of Research and Implications for Teaching and Learning. *Stud. Sci. Educ.* **1995**, *25*, 69–96. [CrossRef]
16. Hofstein, A.; Lunetta, V.N. The Laboratory in Science Education: Foundations for the Twenty-First Century. *Sci. Educ.* **2004**, *88*, 28–54. [CrossRef]
17. Bergmann, J.; Sams, A. *Flip Your Classroom: Reach to Every Student in Every Class Every Day*; International Society for Technology in Education: Washington, DC, USA, 2012; pp. 120–190.
18. Lasry, N.; Dugdale, M.; Charles, E. Just in Time to Flip Your Classroom. *Phys. Teach.* **2014**, *52*, 34–37. [CrossRef]
19. Rowley, N.; Green, J. Just-in-Time Teaching and Peer Instruction in the Flipped Classroom to Enhance Student Learning. *Educ. Pract.* **2015**, *2*, 14–17.
20. Gómez-Tejedor, J.A.; Vidaurre, A.; Tort-Ausina, I.; Molina-Mateo, J.; Serrano, M.-A.; Meseguer-Dueñas, J.M.; Martínez Sala, R.M.; Quiles, S.; Riera, J. Effectiveness of Flip Teaching on Engineering Students' Performance in the Physics Lab. *Comput. Educ.* **2020**, *144*, 103708. [CrossRef]
21. Prasetyo, B.D.; Suprapto, N.; Pudyastomo, R.N. The Effectiveness of Flipped Classroom Learning Model in Secondary Physics Classroom Setting. *J. Phys. Conf. Ser.* **2018**, *997*, 012037. [CrossRef]
22. González-Gómez, D.; Jeong, J.S.; Airado Rodríguez, D.; Cañada-Cañada, F. Performance and Perception in the Flipped Learning Model: An Initial Approach to Evaluate the Effectiveness of a New Teaching Methodology in a General Science Classroom. *J. Sci. Educ. Technol.* **2016**, *25*, 450–459. [CrossRef]
23. Li, Y.; Yuan, Z. Application of Flipped Classroom in University Physics Experiment. In Proceedings of the 1st International Conference on Contemporary Education and Economic Development (CEED 2018), Bali, Indonesia, 17–18 November 2018; Atlantis Press: Paris, France, 2018.
24. Novak, A.; Patterson, E. An Introduction to Just-in-Time Teaching. In *Just-in-Time Teaching: Across the Disciplines, Across the Academy*; Simkins, S., Maier, M., Eds.; Stylus: Sterling, VA, USA, 2010; p. 3. ISBN 978-1579222932.
25. McGee, M.; Stokes, L.; Nadolsky, P. Just-in-Time Teaching in Statistics Classrooms. *J. Stat. Educ.* **2016**, *24*, 16–26. [CrossRef]
26. Turnip, B.; Wahyuni, I.; Tanjung, Y.I. The Effect of Inquiry Training Learning Model Based on Just in Time Teaching for Problem Solving Skill Betty. *J. Educ. Pract.* **2016**, *7*, 177–181.
27. Abd-El-Khalick, F.; BouJaoude, S.; Duschl, R.; Lederman, N.G.; Mamlok-Naaman, R.; Hofstein, A.; Niaz, M.; Treagust, D.; Tuan, H. Inquiry in Science Education: International Perspectives. *Sci. Educ.* **2004**, *88*, 397–419. [CrossRef]
28. Edelson, D.C.; Gordin, D.N.; Pea, R.D. Addressing the Challenges of Inquiry-Based Learning Through Technology and Curriculum Design. *J. Learn. Sci.* **1999**, *8*, 391–450. [CrossRef]
29. Keselman, A. Supporting Inquiry Learning by Promoting Normative Understanding of Multivariable Causality. *J. Res. Sci. Teach.* **2003**, *40*, 898–921. [CrossRef]
30. Linn, M.C.; Songer, N.B.; Eylon, B.S. Shifts and Convergences in Science Learning and Instruction. In *Handbook of Educational Psychology*; Calfee, R., Berliner, D., Eds.; Macmillan: Riverside, NJ, USA, 1996; pp. 438–490.

31. Lederman, N.G.; Lederman, J.S.; Antink, A. Nature of Science and Scientific Inquiry as Contexts for the Learning of Science and Achievement of Scientific Literacy. *Int. J. Educ. Math. Sci. Technol.* **2013**, *1*, 138–147.
32. Eick, C.; Meadows, L.; Balkcom, R. Breaking into Inquiry: Scaffolding Supports Beginning Efforts to Implement Inquiry in the Classroom. *Sci. Teach.* **2005**, *72*, 49–53.
33. de Jong, T.; van Joolingen, W.R. Scientific Discovery Learning with Computer Simulations of Conceptual Domains. *Rev. Educ. Res.* **1998**, *68*, 179. [CrossRef]
34. Bell, R.; Smetana, L.; Binns, I. Simplifying Inquiry Instruction. *Sci. Teach.* **2005**, *72*, 30–33.
35. Hegarty-Hazel, E. Lab Work. *Set Res. Inf. Teach.* **1986**, 1. [CrossRef]
36. Du, W.Y.; Furman, B.J.; Mourtos, N.J. On the Ability to Design Engineering Experiments. In Proceedings of the 8th UICEE Annual Conference on Engineering Education Kingston, Kingston, Jamaica, 7–11 February 2005; pp. 7–11.
37. Chen, Z.; Klahr, D. All Other Things Being Equal: Acquisition and Transfer of the Control of Variables Strategy. *Child Dev.* **1999**, *70*, 1098–1120. [CrossRef] [PubMed]
38. Schwichow, M.; Croker, S.; Zimmerman, C.; Höffler, T.; Härtig, H. Teaching the Control-of-Variables Strategy: A Meta-Analysis. *Dev. Rev.* **2016**, *39*, 37–63. [CrossRef]
39. Zoupidis, A.; Stragas, A.; Kariotoglou, P. The Effect of Explicit Teaching of the Variable Control Strategy on the Understanding of the Method by Female Kindergarten Teacher Students. In *Teaching Science in Preschool Education Challenges and Perspectives*; Kalogiannakis, M., Ed.; Gutenberg: Athens, Greece, 2018. (In Greek)
40. Boudreaux, A.; Shaffer, P.S.; Heron, P.R.L.; McDermott, L.C. Student Understanding of Control of Variables: Deciding Whether or Not a Variable Influences the Behavior of a System. *Am. J. Phys.* **2008**, *76*, 163–170. [CrossRef]
41. Schalk, L.; Edelsbrunner, P.A.; Deiglmayr, A.; Schumacher, R.; Stern, E. Improved Application of the Control-of-Variables Strategy as a Collateral Benefit of Inquiry-Based Physics Education in Elementary School. *Learn. Instr.* **2019**, *59*, 34–45. [CrossRef]
42. Erlina, N. Evidence-Based Reasoning in Inquiry-Based Physics Teaching to Increase Students' Scientific. *Balt. Sci. Educ.* **2018**, *17*, 972–985. [CrossRef]
43. Piskurich, G.M. *Rapid Instructional Design*, 2nd ed.; John Wiley & Sons, Inc: Hoboken, NJ, USA, 2015; ISBN 9781119207528.
44. Pedaste, M.; Mäeots, M.; Siiman, L.A.; de Jong, T.; van Riesen, S.A.N.; Kamp, E.T.; Manoli, C.C.; Zacharia, Z.C.; Tsourlidaki, E. Phases of Inquiry-Based Learning: Definitions and the Inquiry Cycle. *Educ. Res. Rev.* **2015**, *14*, 47–61. [CrossRef]
45. Hackling, M.W. *Working Scientifically: Implementing and Assessing Open Investigation Work in Science*; Department of Education and Training: East Perth, WA, Australia, 2005; ISBN 0-7307-4146-X.
46. Graasp—A Space for Everything. Available online: https://graasp.eu (accessed on 5 May 2022).
47. European Communities. *Science Education NOW: A Renewed Pedagogy for the Future of Europe*; Office for Official Publications of the European Communities: Luxembourg, 2007; ISBN 978-92-79-05659-8.
48. Widowati, A.; Widodo, E.; Anjarsari, P. Setuju. The Development of Scientific Literacy through Nature of Science (NoS) within Inquiry Based Learning Approach. *J. Phys. Conf. Ser.* **2017**, *909*, 012067. [CrossRef]
49. Howley, I. Adapting Guided Inquiry Learning Worksheets for Emergency Remote Learning. *Inf. Learn. Sci.* **2020**, *121*, 549–557. [CrossRef]
50. Natale, C.C.; Mello, P.S.; Trivelato, S.L.F.; Marzin-Janvier, P.; Manzoni-De-Almeida, D. Evidence of Scientific Literacy through Hybrid and Online Biology Inquiry-Based Learning Activities. *High. Learn. Res. Commun.* **2021**, *11*, 33–49. [CrossRef]