Implementation of a Teaching Scenario for Fifth-Grade Students Using the Software “MATHEMA” as a Teaching Tool: The Phenomenon of Light Reflection

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ABSTRACT

In this paper, the implementation of a teaching scenario on the phenomenon of light reflection for 55 students of the fifth grade of primary school is analyzed in detail. The novelty of this teaching scenario lies both in the fact that it is based on the use of the teaching tool/simulation software “MATHEMA” as a cognitive tool and in the fact that the pedagogical approach used is based on the principles of the constructivist approach. This teaching scenario consists of the following two parts: a) The teaching organization guide and b) The students’ worksheets. The SOLO method - taxonomy - is used to assess the learning outcomes. Based on the learning outcomes, a significant shift in students’ responses towards the scientific model was observed after the experimental interventions. Consequently, a conceptual change was achieved, to some extent, after performing the virtual experiments. The results presented in this study support the argument for the learning value and contribution of simulation software as a teaching tool in science teaching and learning.

Keywords: light reflection, simulation software, students, teaching scenario.

I. INTRODUCTION

Through the constant development of technology and the continuous evolution of new innovative technological tools, such as simulation software, Information and Communication Technologies (ICT) seem to be a powerful tool to support teaching and learning in science, including and implementing features required by Science (Evangelou & Kotsis, 2019; Jimoyiannis et al., 2000; Jimoyiannis & Komis, 2001; Psillos et al., 1993; Psillos, 2007; Psillos, 2023; Taramopoulos et al., 2010; Taramopoulos et al., 2012; Taramopoulos & Psillos, 2018; Tsihouridis et al., 2018; Tsihouridis & Vavougios, 2023; Zacharia & Olympiou, 2011).

The rapid development of ICTs and their applications in teaching and learning of science are therefore creating powerful new learning environments (Anam et al., 2023; Psillos, 2007; Psillos, 2023; Taramopoulos & Psillos, 2018; Tsihouridis & Vavougios, 2023). The literature presents multiple examples of the effectiveness of simulations in developing content knowledge, conceptual change, and skill cultivation, as well as in supporting teaching models and theories such as conceptual change (Bell & Smetana, 2008; Jaakkola & Nurmi, 2008; Taramopoulos et al., 2010; Taramopoulos et al., 2012; Zacharia & Olympiou, 2011). In other words, software integration into teaching practice is achieved through appropriately structured teaching scenarios that use it in the context of that practice as a cognitive tool (Mikropoulos, 2006). The teaching scenarios determine the form of activities performed in the environment and the way and degree of guidance of the user’s actions by the teacher or the software (Baumgartner, 2011; Pedro et al., 2019; Taramopoulos, 2012; Taramopoulos et al., 2012).

Based on the above, in order to determine the effectiveness of ICT in the teaching of Science, this paper attempts to implement a teaching scenario for fifth grade students at primary school on the phenomenon of light reflection using the software “MATHEMA” as a teaching tool.

II. THE SOFTWARE “MATHEMA” AS A TEACHING TOOL

In the present research, the Optics laboratory and in particular, the module “Reflection in a mirror” of the educational software “MATHEMA” (Fig. 1). This module includes the simulation of a Geometric Optics laboratory, where the student can continuously vary the angles of the mirrors and observe the direction of the light beam after the light beam is reflected in a mirror (Tekos & Solomonidou, 2008). Furthermore, with the geometric model, the student is asked to measure the angles of incidence and reflection and can also repeat the measurements by rotating the mirror and fixing it in different positions.

Finally, the student can be guided to understand basic concepts of Geometric Optics by verifying his/her predictions and checking his/her ideas through the suggested activities. For this purpose, the user is provided with the possibility to observe in a separate window the respective
dynamic geometric model (Fig. 1) representing the phenomenon under study. The student can continuously vary the angles and distances of mirrors, plates, etc., from the light source and observe the direction of the light beam after reflection in a mirror (Solomonidou, 2001).

![Fig. 1. The screen of the MATHEMA simulation software in the “Reflection in a mirror” section.](image)

III. METHODOLOGY OF THE RESEARCH

A. The Purpose and the (Inter)Research Question of the Research

The main purpose of the present study is to investigate students’ conceptual understanding and learning outcomes after implementing a teaching scenario in which they perform virtual experiments using the software “MATHEMA” as a teaching tool on the phenomenon of light reflection.

The (inter)research question of the present research is the following: “Is a conceptual change (conceptual understanding) achieved in fifth-grade students after performing experiments with the “MATHEMA” software on the phenomenon of light reflection?”

B. The Sample

The sample, consisting of a total of three (3) primary schools, was selected from a list of twenty-seven (27) primary schools in the city of Ioannina (Greece) using cluster random sampling (Cohen et al., 2000). The sample of the study consisted of 55 fifth-grade students.

C. Data Collection

Data collection for this study was done by administering worksheets given to the students both before and after the implementation of the teaching scenario.

It is worth noting that the questions given to students -with worksheets available in the Appendix—were exactly the same before and after performing the mock experiments. At the same time, they individually completed the worksheets with which the data were collected.

The students used the computer laboratory to perform the virtual experiments using the simulation software “M.A.T. E.H.M.A.”

The experiments were performed by the students themselves, who were in pairs in the computer lab.

IV. THE TEACHING SCENARIO

The teaching scenario constitutes an integrated learning framework, a structured way of organizing teaching that includes successive stages to build knowledge (Mikropoulos & Bellou, 2010). At the same time, it utilizes specific “conventional means,” and in the case of the present study supported by ICT, it utilizes specific educational tools/teaching resources, such as the simulation software “MATHEMA” (Baumgartner, 2011; Dagdilelis et al., 2011; Mikropoulos & Bellou, 2010; Pedro et al., 2019).

The teaching scenario in this paper consists of two parts: a) The teaching organization guide and b) The students’ worksheets.

The originality of our approach lies in the execution of the virtual experiments based on the principles of the constructivist approach (Kariotoglou, 2006; Koumaras et al., 1992; Psillos et al., 1993) and the use of the teaching tool/software “MATHEMA” as a cognitive tool.

The total duration of the scenario is estimated at (2) teaching hours (90 minutes). The scenario is addressed to students who have little experience in performing virtual experiments using simulation software.

The experiments are conducted in the computer laboratory (or in the classroom using laptops), where students work in pairs.

A. Teaching Goals

Students are sought:

1) Experimentally determine the phenomenon of light reflection and in particular, the property of light to reflect (change its path) when it falls on smooth (glossy - shiny) surfaces, such as a mirror.

2) To establish experimentally the law of reflection (a property of the phenomenon of reflection) and in particular, that the angle formed by the incident ray of light with perpendicular to the point of incidence on a mirror is equal to the angle formed by the reflected line with the same perpendicular (the angle of incidence is equal to the angle of reflection)

3) Distinguish between the incident and the reflected ray of light.

4) Make predictions - hypotheses, observations, experimental tests of predictions and hypotheses through experimentation and be able to formulate conclusions.

5) To modify and change their alternative ideas to scientifically correct ideas about the concept of light reflection (conceptual change).

B. Proposed Course of Instruction-Phases of Instruction

Based on the principles of the constructivist approach and in particular, the (5) phases of the “constructivist teaching strategy model” (Psillos et al., 1993; Kariotoglou, 2006), the following steps are proposed:

1) Phase (1): Trigger of interest - Emergence of students’ ideas: The teacher triggers the students through general questions and also questions contained in the initial worksheet (1), to orient and arouse their interest in the phenomenon of light reflection.

2) Phase (2): Predictions - Assumptions - Emergence of ideas: The teacher, through discussion and with the worksheets (2)-Predictions-Hypotheses given to the students, asks the students, through hypothetical experiments, to predict and formulate hypotheses about the causes, function, evolution, and results of the phenomenon of light reflection (Kokkotas et al., 2002).

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3) Phase (3): Testing the ideas and introducing the scientific model- Drawing conclusions: the teacher, after the formulation of the students’ predictions and hypotheses, activates the students to perform virtual experiments using the worksheets (3) and the “M.A.T.H.E.M.A.” software, to then formulate and evaluate their observations.

4) Phase (4): Application of the scientific model- Generalisation: The teacher invites students to complete the worksheet (4)-Applications.

5) Phase (5): Review and compare students’ ideas with the ideas of the science model-Metacognitive phase - Embedding: The teacher asks the students to describe their old and new knowledge and to perceive the differences between them (Psillos et al., 1993; Kariotoglou, 2006).


There are two (2) virtual experiments performed by students on the phenomenon of light reflection. They are related to the first three teaching objectives mentioned above in the subsection: “Teaching goals" and are detailed in the worksheets available in the Appendix of this research.

V. ASSESSMENT OF THE RESPONSES

The evaluation of student responses before and after performing the real and virtual experiments was done according to the Biggs and Collis (1982) Structure of the Observed Learning Outcomes (SOLO) model. The SOLO taxonomy model is based on the theory that knowledge is gained through building blocks. It is a powerful tool that determines a person’s current operational level and conceptual knowledge through written or spoken answers. It can be applied to any subject area and provides the ability to evaluate and categorize students’ performance (Bellou, 2003; Padiotis & Mikropoulos, 2010). Based on the SOLO taxonomy, a response can be integrated into one of the following five (5) hierarchical levels:

1) Prestructural: Students do not provide an answer, or they provide the incorrect answer without giving any explanation for their choice, or they provide the incorrect answer due to incorrect associations.

2) Unistructural: Students make simple and obvious associations but do not demonstrate the relationship among these associations.

3) Multistructural: Students make several associations but do not demonstrate the relationship among these associations.

4) Relational: Students demonstrate the relationship between associations and the relationship between the associations and the end result

5) Extended abstract: Students make associations outside the subject area, generalize and transfer laws-relationships from the specific to the general.

In the present study and based on the above classification, student answers were graded using the first four hierarchical levels, as these consider the degree of answer elaborateness. The four SOLO taxonomy levels in this study include (1) Prestructural, (2) Unistructural, (3) Multistructural, and (4) Relational. Answers that meet the requirements of the SOLO taxonomy extended abstract level (level 5) were not observed in any of the questions on the pre-and post-tests (worksheets).

VI. RESULTS

The General Linear Model (GLM) and the statistical package STATISTICA 8.0 were used for the statistical analysis of the data. In this paper, the results for questions (1) of worksheets (1) and (4) are analyzed as an example.

More specifically, for the fifth-grade students, the learning outcomes are coded, before and after the experiments, in the following Table I:

| TABLE I: RECORDING (ABSOLUTE AND RELATIVE FREQUENCY) OF SOLO COGNITIVE LEVELS (PRE–POST) OF FIFTH GRADE STUDENTS IN QUESTION (1) |
|-------------|----------|----------|
| Level       | PRE      | POST     |
|             | N        | Perc. (%)| N        | Perc. (%)|
| Prestructural| 20      | 36.4     | 6        | 10.9     |
| Unistructural| 29      | 52.7     | 19       | 34.5     |
| Multistructural| 6      | 10.9     | 18       | 32.7     |
| Relational  | 0        | 0        | 12       | 21.8     |

Table I shows that in question (1) before the experimental intervention, only 6 students (10.9%) classified their answers in the two higher levels, i.e., from Multistructural to Relational level, where in this last level, the correct answers are included. On the contrary, after the intervention using the “MATHEMA” software, the answers from 30 students were classified in these two higher levels, i.e., 54.5%. Consequently, for the students, there is a significant improvement in learning outcomes towards the two higher levels after the intervention. It becomes evident that a large extent, conceptual change was achieved after the experiments were carried out.

In question (2) before the experimental intervention, the answers of only 2 students (3.6%) were classified in the two higher levels. In contrast, after the intervention, the responses from 26 students were ranked at these two higher levels, i.e., 47.3%.

In question (3) before the experimental intervention, no responses (0%) from students were classified in the two higher levels. In contrast, after the intervention, 23 students’ responses from 23 students were classified in these two higher levels, i.e., 41.8%.

VII. CONCLUSION

Based on the learning results, after the experimental interventions, a significant shift in students’ answers (in all questions) towards the two higher cognitive levels approximating the scientific model was observed, which, based on the SOLO taxonomy, is sometimes approximated by the Multistructural level and is perfectly identical to the Relational level. Consequently, it becomes evident that a conceptual change was achieved, to some extent, after the execution of the virtual experiments. This means that percentage of students’ alternative ideas are getting closer and more compatible with the scientific model.
The results presented in this study support the argument for the learning value and contribution of simulation software in science teaching and learning. Using simulation software in combination with the instructional paradigm of constructivism can bring about positive results in the conceptual understanding of phenomena (e.g., light reflection) and the cultivation of skills in science.

In other words, the use of ICT and, in particular, the simulation software “MATHEMA” through targeted science teaching scenarios effectively contributes to the development of content knowledge, the cultivation of skills, and the support of teaching models and theories such as constructivism and conceptual change (Bell & Smetana, 2008).

At the same time, it is worth pointing out that the optimal way of using simulation software, such as M.A.T.H.M.A., in the teaching process of science creates powerful new learning environments (Psillos, 2007, 2023) that do not lag behind real laboratories.

However, it should be noted that virtual experiments using simulation software are not a panacea in the learning behind real laboratories.

Step 1: With a simple click, lower the mirror and the light bulb (with bulb)-headlight-onto the bench.

Step 2: Turn on the light bulb by clicking on the switch.

Step 3: Place the mouse on the white part of the lamp. As soon as a hand appears, press the left consecutive click and hold it down until the light beam falls on any point on the vertical mirror.

APPENDIX

Worksheet (1):

1) Can you explain why we often go blind in the summer when the sunlight hits the car mirror?
2) Can you explain why the mountains and trees can be seen in the calm waters of the lake in the picture below?

3) What happens to a beam of light when it hits the glass window of a shoe store? Justify your answer.

Worksheet (2):

It contains the same activities as a worksheet (3) presented below, except that it asks students to make predictions of the experiments.

Worksheet (3):

First experiment

Step 1: With a simple click, lower the mirror and the light bulb (with bulb)-headlight-onto the bench.

Step 4: On the right hand side of the Geometric Model, carefully observe the degrees of the angle that the angle formed by the ray incident on the mirror with the perpendicular line at the point of incidence of the mirror and the angle formed by the ray reflected from the mirror (angle of reflection) with the same perpendicular line.

Step 5: Observe in the “Geometric Model” (shown on the screen above) the sides that the incident ray forms with the perpendicular line at the point of incidence of the mirror and the reflected ray forms with the same perpendicular line.

REFERENCES

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