European Journal of Education Studies
ISSN: 2501 - 1111
ISSN-L: 2501 - 1111
Available online at: www.oapub.org/edu

DOI: 10.46827/ejes.v10i12.5088 Volume 10 | Issue 12 | 2023

TEACHING PHOTOSYNTHESIS USING AN INQUIRY-BASED APPROACH VIA A DIGITAL EDUCATIONAL PLATFORM TO PROMOTE STUDENTS' UNDERSTANDING

Maria Fermani,
Martha Georgiou[i]
Department of Biology,
National and Kapodistrian University of Athens,
Greece

Abstract:
Our research aimed to identify whether inquiry-based learning via Go-LAB platform, could enhance students learning about photosynthesis. The study sample consisted of 92 second-year high-school students, and the educational intervention consisted of three teaching hours. We conducted a pre- and a post- test via a questionnaire with closed-ended questions to detect the possible results of our teaching intervention. The statistically significant difference between the pre- and post-test surveys indicated that the inquiry-based intervention via Go-LAB platform helped students to better understand the concept of photosynthesis. At the same time, positive learning effects in our study were found to be gender-independent, a finding that is in line with a multitude of studies. Students gave more correct answers about the photosynthesis process, and several alternative ideas seemed to be overturned. Consequently, according to our findings, inquiry-based learning supported by the Go-LAB platform seems to represent an efficient way of teaching complex biological concepts like photosynthesis.

Keywords: inquiry-based learning, photosynthesis, digital educational platform, secondary education, learning outcomes, Go-Lab

1. Introduction

It is commonly known that students worldwide do not show encouraging performance in Science education (Gökhan, 2012). Greece is characterized as a low-achieving country according to PISA results, with Greek students scoring below average in Science (OECD, 2018). Poor academic performance is a prime indicator of the ineffectiveness of educational systems (Aremu & Oluwole, 2001), and combined with the apparent lack of students' interest, brings about the need to develop novel teaching approaches. To improve students' performance in Science, various teaching approaches have been

[i] Correspondence: email martgeor@biol.uoa.gr

proposed, including inquiry-based learning (Pedaste et al., 2015a, 2015b), the use of drama in Science teaching (Marmaroti & Galanopoulou, 2006), or the use of technological teaching-enhancements (Ray & Beardsley, 2008; Kici, 2012). Inquiry-based learning has been widely recognized as an improvement compared to traditional teaching (Ray & Beardsley, 2008; National Research Council, 1996) with several countries already having incorporated it into their curricula (Lee, 2012) as it has been consistently shown that it is more effective than expository instructional approaches, as long as students are supported adequately by the teacher (Lazonder & Harmsen, 2016). The apparent success of inquiry-based learning can be attributed to its propensity to be enhanced by recent technological enhancements, and especially by electronic learning environments (National Research Council, 1996). In our era, it is clearly evident that science and technology education plays a key role in societal prosperity (Karamustafaoglu, 2010).

2. Theoretical Background

2.1 Inquiry-based Learning in Science Education

The term ''inquiry-based learning'' generally refers to student-centered ways of teaching, in which students raise questions, explore situations, and develop their own paths towards learning (Artigue & Blomhøj, 2013). Nevertheless, accurately defining inquiry-based approaches has proved difficult (Spronken-Smith et al., 2014) as it can be used to describe exploration-based teaching approaches, as well as common scientific practices (Colburn, 2000). Even among teachers, some educators focus on inquiry-based learning as a teaching strategy, while others define it as awareness's impairment of the essence of research to students (Abed, 2014). As a result, different terms and concepts of inquiry-based learning are used or highlighted (Zion & Mendelovici, 2012), giving rise to diverse teaching models with a core-set of common aims (Zion & Sadeh, 2007) More specifically, the utility of the inquiry-based model, which is considered as a very effective teaching method, remains controversial amongst educators (Zion & Mendelovici, 2012): some teachers prefer using the structured inquiry, while others prefer using the open inquiry (Zion & Mendelovici, 2012). Nevertheless, the majority of previous reports have shown that guided inquiry has the most beneficial effects on teaching (Mulyana et al., 2018; Bruder & Prescott, 2013).

Some studies support the efficacy of guided inquiry in improving students' performance (Alfieri et al., 2011; Furtak et al., 2012), motivating students to learn (Ferguson, 2010), improving their stance on science (Brune, 2010; Idleman, 2012), as well as on scientific literacy (Gengarelly & Abrams, 2009). Furthermore, secondary education students seem to be the best target of inquiry-based approaches, since they are fully capable of abstract thinking (Doukeli, 2013). Thus, biology education and biological literacy could benefit from this teaching method, as learning is better served and students come in contact with the core of this subject. Needless to say, biology is not only theoretical but needs embedded experimentation and a basic scientific approach like all subjects in Science. Anything that could serve in this direction could be very fruitful for students aiming to learn biological concepts, procedures, and phenomena, and digital technology has lately been proven to play an important role in promoting inquiry-based learning (Domouctsidou, 2012).

2.2 Combining ICT and Inquiry-based Learning in Biology Teaching: The Go-Lab Platform

Nowadays, digital applications gain ground when combined with several teaching methods as they lead to better learning outcomes not only in biology but in Science generally. Davies et al. studied the effects of creative electronic environments in school settings, and noticed significant benefits, such as improvements in academic performance and increased student motivation (Davies et al., 2013). Studies have shown that combining text, sound, and colorful animation attracts students to learning (Tinio, 2003). Computer-based approaches (ICT) are receiving increased attention from the community of science educators, owing to their potential to support not only academic performance but also new forms of inquiry (Davies et al., 2013; Wurst et al., 2008; Brown & Edelson, 2003; de Jong et al., 2014). Due to ICT, virtual experiments may be carried out by students who otherwise may not have the opportunity to perform real experiments on school grounds. In addition, students' interest and engagement seem to be increased, and consequently student performances, and predisposes a positive turn towards biology (Robinson, 2017; Zhang, 2010).

According to the aforementioned, it is not surprising that there have been a multitude of newly developed electronic learning environments focused on biology lately (Schmidt & Jirstrand, 2006; Moreland et al., 2005; Akpan, 2001; Carlsson, 2003). However, apart from specifically subject-oriented learning environments (e.g., physics, chemistry, biology), there are generally science-oriented environments that provide distinct spaces for each subject.

One of these digital learning environments is the Global Online Science Labs for Inquiry Learning at School (Go-LAB) platform (de Jong et al., 2014).

This platform is the result of a cooperative European program involving 11 countries. It is committed to promoting and supporting STEM education (Schneegass et al., 2006), which is based on Inquiry Learning Spaces (ILS) (de Jong et al., 2014), and has been created to provide teachers, educators, and researchers the opportunity to create digital scenarios structured on specific axes according to inquiry-based learning without any cost (de Jong et al., 2014). Hence, students following the learning steps in such a teaching approach (an ILS created in the Go-Lab platform) form their own hypotheses, design and perform experimental procedures to check those hypotheses and come to conclusions. On the other hand, all ILS creators can share their work, enriching the possible teaching suggestions for all the scientific and teaching community. These specific characteristics led us to select the Go-LAB platform as a means to apply inquiry-based learning in biology to assess the efficacy of this learning model when combined with digital tools in the case of photosynthesis. Also, as previous studies have reported conflicting results on whether male students benefit more from digitally supported approaches when compared to their female counterparts (Jagannath, 2013; Park et al., 2009; Fakomogbon et al., 2014; Basturk, 2005), we decided to evaluate whether teaching via an inquiry-based learning platform may have different results according to gender.

2.3 Teaching and Learning about Photosynthesis

Photosynthesis has a ubiquitous presence in school curricula (Stavy et al., 1987), but is a complex biological phenomenon (Stavy et al., 1987) and students quite often display insufficient levels of realizing its significance (Ray & Beardsley, 2008) and processes that govern it. As such, photosynthesis has been rated as one of the most difficult topics for students to understand (Waheed & Lucas, 1992). Due to its numerous conceptual aspects (ecological, physiological, biochemical, and energetic), photosynthesis is a complex and difficult biological topic connected in a multitude of ways that cannot be easily grasped by students (Waheed & Lucas, 1992). Misconceptions have been recorded for each of these aspects of photosynthesis (Waheed & Lucas, 1992). Moreover, studies have shown that students often have alternative ideas on how plants feed themselves (Driver, 1989). Most students attribute a heterotrophic mode of feeding to plants, analogous to that of animals, determining the soil, the air, or the sun, as potential food sources (Barker & Carr, 1989), with the most common alternative idea being that their food comes from the soil (Marmaroti & Galanopoulou, 2006; Bell, 1985; Eisen & Stavy, 1993). Furthermore, although many students believe that plants do need sunlight in order to live and develop, only a minority could accurately explain the function of sunlight in relation to green plants (Bell, 1985; Bishop et al., 1986). The concept of energy conversion also seems to be a complicated concept for secondary education students (Ryoo & Linn, 2012). Consequently, without properly understanding the concept of energy conversion during photosynthesis, students would not be able to apply their knowledge of energetical properties and realize where energy originates from in living ecosystems (Ryoo & Linn, 2012). In Greece, photosynthesis is included in the curriculum of the first and third grades of lower secondary school (K7 and K9), but in an indirect way in K9, which is the last school year of compulsory education.

It is obvious that educators should develop various ways of teaching to promote a better understanding of photosynthesis. The aim of our research is to evaluate the efficacy of an inquiry-based teaching approach combined with digital facilities as those of the Go-LAB platform, in photosynthesis learning. Consequently, the research questions that arose were the following

1) Can the inquiry-based learning model through an appropriate digital platform improve learning outcomes concerning photosynthesis?
2) Are these learning outcomes gender-dependent?

3. Methodology

A quantitative research method was chosen, and Go-LAB was the educational platform that we used to teach photosynthesis through an inquiry-based approach. A pre- and post-test were used to assess students' prior knowledge about photosynthesis and their knowledge after the three-hour teaching intervention.

3.1 Participants

Our research sample was a convenience sample consisting of ninety-two (92) 9th-grade students. Sixty-one (61) of them were from a school on a small Dodecanese island, and thirty-one (31) from an urban school in Athens; in total, 40.2% (37) were males, and 59.8% (55) were females. Students were divided into six groups of 15-16, and they all were at the same knowledge level concerning photosynthesis. This was ensured by assessing their performance in a questionnaire regarding photosynthesis[6] which was distributed to them prior to the teaching intervention. Students had no previous experience in using the Go-LAB platform.

3.2 Research Tools

3.2.1 Pre-test

A questionnaire with closed-ended questions was distributed to the participants before the teaching intervention in order to assess their level of knowledge. (Students participating in the questionnaire have already been taught about photosynthesis in previous grades.) The questionnaire developed by Marmaroti and Galanopoulou (2006) and modified by us was and consisted of 11 multiple-choice questions, to which students were asked to give the best possible answer. To be more specific, we removed the questions concerning the connection between photosynthesis and cellular respiration, keeping all the rest of the questions. (It should be noted that only the best possible answer was considered correct.) The removal of these questions was decided as our teaching intervention was based on the corresponding curriculum of K9 which does not refer to the connection between photosynthesis and respiration. Closed-ended questions provided us with direct and quantitative data, informing us on pre-existing alternative ideas and misconceptions of 9th-graders on photosynthesis. Furthermore, the questionnaire had the advantage of being designed by Greek researchers based on the goals of the Greek curriculum, and had already been applied in Greek schools. It was based on Tamir's (1991) alternative approaches to constructing multiple-choice tests, so that the results indicate not only the number of students that chose the correct answer, but also how many students held misconceptions (Tamir, 1991). Regarding the understanding of each aspect, the questionnaire includes complementary or logically related questions focusing on specific aspects of photosynthesis: Physiology, Photosynthesis and energy, Photosynthesis as a chemical reaction, Autotrophy, Photosynthesis, and the function of the ecosystem.

3.2.2 Post-test

A questionnaire with closed-ended questions was also used one day after the teaching intervention. It focused on the same five aspects of photosynthesis as the pre-test. For each aspect, two to eight questions were formulated in different manners, in order to evaluate students' knowledge of the same concepts (see Appendix A). Construction of this questionnaire was considered as necessary in order to avoid students' noticing recurring questions, which would decrease the motivation of students and could potentially distort the results. Furthermore, multiple similar questions were used in order to detect potential random answers from the students (see Appendix A).

The face validity of the questionnaire was assessed by seven university professors in the fields of biochemistry and biology education, by a researcher in the field of photosynthesis, and by two experienced secondary education teachers. They were also asked to confirm the classification of the questions within the corresponding sections and to grade the difficulty level and the scientific accuracy of the questions according to their opinion. Since multiple-choice questions have been found to be interpreted differently by individuals, we accounted for question misinterpretations. Specifically, a pilot study was conducted with the help of 10 volunteer students (Biology and Primary Education Departments) and afterward with the help of 10 volunteer 9th-grade students. The aims of the pilot study were to ensure that 1) the questions were adequately, unambiguously, and concisely expressed (Javeau, 2000), 2) the questions were of an appropriate difficulty level, 3) the desired data could be derived from the questions. Results of the pilot study suggested that the constructed questionnaire achieved all the necessary criteria to be further implemented.

3.3 Educational Scenario

Given that the internet-based Go-LAB platform was used in our teaching intervention, we recommended that personal computers with internet access be the minimum infrastructure needed to apply our intervention. Students of each group worked in teams of two, each team having one personal computer, since team-based learning has been shown to improve learning outcomes (Matsaggouras, 2000).

Initially, we presented the Go-LAB so that they became familiar with it. Afterwards, they were informed about the ILS created by the researchers concerning photosynthesis. More specifically they were informed about all the steps that they would follow (i.e. short introduction, hypothesis, experimentation, conclusion) during our teaching intervention. In more detail, the three-hours teaching intervention focused on the process of photosynthesis, the role of chlorophyll and sunlight, the factors that affect the rate of photosynthesis, and the importance of photosynthesis for ecosystems.

3.4 The Photosynthesis Process

At first, students were asked to answer how humans and other animals ensure the required energy for their survival. Next, they were asked their opinion on how plants ensure the required energy for their survival. Students submitted their hypotheses through the Hypothesis Scratchpad (figure 1) of the Go-LAB platform (Hong et al., 2014). This aimed to highlight potential student misconceptions on photosynthesis, in order to afterwards assess whether the intervention alleviated them. Subsequently, a video was presented to students ("Photosynthesis and (my own) Indiana Jones"), which delineated a story wherein students were investigators, working under King Austin of Lost Atlantis, assisting and spying on Indiana Jones while he was on his quest to discover the historical experiments on photosynthesis. The choice of studying photosynthesis through revisiting historical experiments was not random; it is widely accepted that utilizing the history of scientific discoveries to teach science cultivates critical thinking in students (Malamitsa et al., 2005). *"Historical reading combined with investigative experimentation, especially of a historical nature, appears to be a promising way for students to learn the basics of the scientific method and understand some other issues of the nature of science even when this subject is presented unobtrusively"* (McComas, 2002) (Jan Ingenhausz experiment, van Helmont experiment, Joseph Priestley experiment, John Woodward experiment) that led to photosynthesis understanding.

3.5 The Role of Chlorophyll and Sunlight

Subsequently, students attempted to realize the roles of chlorophyll and sunlight in photosynthesis. They were asked about the importance of chlorophyll in photosynthesis, and were asked to write down their responses using the Hypothesis Scratchpad of the Go-LAB platform. Additionally, they attended a PowerPoint presentation ("Alice in Plantland!"), which presented the quest of Alice and her guide (a biology student named Alex), in which the structure of the main photosynthetic organ (a leaf) was described. Also, students watched two videos related to the structure of chloroplasts and to experimental procedures for starch identification in plant leaves. After the presentation, students were asked to help Alice discover how plants without chlorophyll could survive and they were asked to form their conclusions on the role of chlorophyll and sunlight and compare these with their original premises.

3.6 Factors That Affect the Rate of Photosynthesis

Next, the students studied the effect of various factors on the rate of photosynthesis, by designing an *in-silico* experiment, followed by experimental validation of their hypotheses on the subject, by utilizing the virtual laboratory Photolab (figure 2). Virtual laboratories act as supplements to physical labs by allowing students to perform virtual experiments (Paxinou et al., 2022). At this point, students were asked to predict which factors affect the rate of photosynthesis, and their replies were deposited again in the Hypothesis Scratchpad of the Go-LAB platform. Next, students designed virtual experiments to check the effects of these factors on photosynthesis and validated their hypotheses through Photolab. Their conclusions followed were compared to their initial hypotheses.

3.7 The Importance of Photosynthesis for Ecosystems

Apart from all the above concepts and procedures, the role of photosynthesis in ecosystems was also examined. Teaching the significance of photosynthesis for living ecosystems was carried out by constructing a virtual food chain, through a tool available in the Go-LAB platform. We first asked for students' opinion about photosynthesis' importance in ecosystems. Next, students designed their own virtual food chains in order to realize the importance of plants within the energy cycle of ecosystems. Finally, students were, also, asked to formulate their conclusions on the role of photosynthesis for life on earth and to conduct the same comparison as every time.

3.8 Data Collection and Analysis

The pre-test was distributed to the students before the three-hour teaching intervention, while the post-test was distributed one day after the intervention. Overall, we collected 92 completed pre-test questionnaires (they were distributed two days before the teaching intervention as already mentioned) and 92 post-test questionnaires.

We statistically compared the overall level of photosynthesis learning of the students, before and after the teaching intervention comparing their answers to the closed-ended questions of the questionnaires using the IBM SPSS 24. We also tested for any gender-dependent differences in the learning outcomes.

4. Results

The intra-questionnaire reliability of the post-test was calculated by the Guttman index for each one of the 16 items (Figure 3). For every subcategory, the λ-2 values were higher than 0.88, meaning that more than 88% of the variance in the students' answers reflected differences in their knowledge levels, while a small percentage (<12%) reflected random errors. Thus, the post-test questionnaire was appropriate for detecting and evaluating the knowledge level of students on photosynthesis. We did not conduct an analogous intra-questionnaire reliability study for the pre-test, as its reliability had already been evaluated by previous studies (Marmaroti & Galanopoulou, 2006).

The statistical analysis was applied in order to test whether there is a statistically significant difference in performance scores, before and after the teaching intervention. Non-parametric statistical tests were chosen to check for differences between the pre- and post-test as our sample was not normally distributed ($D_{before(184)}$= .129, p<0.001, and $D_{after(184)}$ = .163, p =<0.001).

Students' knowledge about photosynthesis was statistically significantly better after the intervention (Mdn=93.0) than before the intervention (Mdn=80.91) (U=1782,5, p<.001).

No statistically significant differences were recorded between the two genders. (U=936.0, p=0.516>0.05). Therefore, positive learning outcomes stemming from the inquiry teaching intervention via Go-LAB platform seem to be gender-independent.

5. Discussion

Our research aimed to identify whether inquiry-based learning via the Go-LAB platform, could enhance students learning about photosynthesis. Hence, we conducted a pre- and a post- test via a questionnaire with closed-ended questions to detect the possible results of our teaching intervention. The statistically significant difference between the pre- and post-test surveys indicated that the inquiry-based intervention created using the Go-LAB platform helped students to better understand the concept of photosynthesis. At the same time, positive learning effects in our study were found to be gender-independent, a finding that is in line with a multitude of studies suggesting that digital supported learning benefits both genders equally (Jagannath, 2013; Basturk, 2005; Ash, 2005; Yusuf & Afolabi, 2010; Dantala, 2006). In more detail, students gave more correct answers about photosynthesis process, the role of chlorophyll and all the factors that affect the phenomenon, and the importance of photosynthesis for ecosystems. Several alternative ideas seemed to be overturned. For example, only a small number of students kept believing that soil comprises the food of plants, but as it is well known one of the characteristics of alternative ideas is that they cannot be easily substituted, as they are experiential most of the time (Driver et al., 1999). Consequently, according to our findings, inquiry-based learning supported by the Go-LAB platform seems to represent an efficient way of teaching complex biological concepts like photosynthesis.

Of course, the number of participants is not large enough to lead to generalization, but it is probable that these results could be taken into consideration (at least as a first impression) in Greece or similar educational systems, as our era represents a golden chance for schools to adapt to novel educational approaches, within a broader effort to support teaching and learning within the fields of Science. Furthermore, the probability of positive contributions in teaching through an inquiry-based digital platform could also be indirectly estimated through the proven positive outcomes of using inquiry-based teaching approaches (Idleman, 2012; Conway, 2017; Omokaadejo, 2015). However, until today, in the literature, there is only one similar research project evaluating the improvement of students' argumentation skills (Georgiou et al., 2019) after an inquiry-based intervention via Go-LAB, although it is proven that inquiry-based teaching has synergistic effects when digitally supported (Pedaste et al., 2015a, 2015b). Thus, as there are no other studies evaluating the efficacy of this combination in improving learning quality, it is difficult to provide any comparative data. Our study highlights the need to initiate a more formal evaluation process of inquiry teaching approach supported by a digital educational platform. Attention should be given to the variation both across and within classrooms after such interventions to shed light on the improvement process of the learning outcomes in science education, generally, and biology education, more specifically.

In this study, we focused on the needs of the students. However, over the course of this effort, we have become increasingly aware of the challenges that a digital educational platform that supports inquiry-based learning poses for teachers. Our experiences have convinced us that supporting the role of the teacher raises important additional challenges for the design of virtual learning environments. Such an issue has been being explored since 2000 for other educational innovations used in the classroom, such as the portfolio (Brown & Edelson, 2003).

6. Limitations and Implications of the Study

The Go-Lab has been developed in accordance with outcomes of pedagogic and scientific research as well as with the users' feedback and experiences from their practices, and it seems it will meet the needs of promises to be a digital platform to enhance inquiry-based learning (Ziogka et al., 2019). The present study contributes by providing an incentive for further studies on the promotion of this kind of teaching approach. Nevertheless, it is likely that the two meetings, during which the teaching intervention took place, were not enough for students to develop a significant increase in their level of understanding. Future research should ensure that students are given enough time to become more familiar with the platform. In addition, the sample size was relatively small, so although we got some very interesting results, no generalizations could be made and the results, even if they seem to be promising, are indicative, and further research with a larger student sample is required. Additionally, our study did not aim to compare the adequacy and efficacy of educational inquiry-based platforms, like the Go-Lab, to traditional teaching methods, as this would require wider and more long-lasting research according to experimental design research. However, we believe that we have captured a first positive trend which is promising regarding a technology-supported teaching model. It is also important to note that we do not refer to the Go-LAB inquiry teaching approach as a "panacea" to improve the performance of any student, the quality of any subject, or the daily routines within classrooms but as an appealing and effective method that could be used as an alternative, especially in cases were no real labs can be carried out.

Conflict of Interest Statement
The authors declare no conflicts of interest.

About the Authors
Maria Fermani is a Biologist with a Master's degree in Biology Education. She has also attended trainings in Adult Education and Special Education. She currently teaches in secondary education.
Martha Georgiou is a full-time instructor and researcher at the Department of Biology of the National and Kapodistrian University of Athens, specializing in Biology Teaching (BSc in Biology, MEd and PhD in Science Education). She teaches "Science/Biology Education" at undergraduate and postgraduate levels in the same department as well as in other departments in Greece and abroad (University of Sorbonne). She has authored articles, and chapters in books and she has also participated in national curriculum writing groups.

References

Abed, N. (2014) Effective Inquiry-Based Learning Strategies in Teaching Science to a Group of High School Learners, Springfield, MA: American International College; Doctoral Thesis.

Akpan, P. (2001) Issues associated with inserting computer simulations into biology instruction. EJSE. 5, 17-18.

Alfieri, L., Brooks, J., Aldrich, N.J. & Tenenbaum, H.R. (2011) Does discovery-based instruction enhance learning? J. Educ. Psychol. 103, 1-18.

Aremu, A.O. & Oluwole, D.A. (2001) Gender and birth order as predictors of normal pupil's anxiety pattern in examination. Ibadan J. Educ. Stud. 1, 1-7.

Artigue, M. & Blomhøj, M. (2013) Conceptualizing inquiry-based education in mathematics. ZDM. 45: 797–810.

Ash J. (2005) The effectiveness of computer-assisted instruction on middle school mathematics achievement. Tennessee, TN: Tennessee State University Doctoral Thesis.

Barker, M. & Carr, M. (1989) Teaching and learning about photosynthesis. Part 1: An assessment in terms of students' prior knowledge. Int. J. Sci. Educ. 11, 49-56.

Basturk, R. (2005) The effectiveness of Computer-Assisted Instruction in teaching introductory statistics. Educ. Technol. Soc. 8, 170-128.

Bell, B. (1985) Students' ideas about plant nutrition: What are they? J. Biol. Educ., 19, 213-218.

Bishop, B., Roth, K. & Anderson, C. (1986) Respiration and Photosynthesis: A Teaching Module. (Occasional Paper No. 90). East Lansing Michigan State Univ. Inst. Res. Teaching.

Brown, M. & Edelson D. (2003) Teaching as design: Can we better understand the ways in which teachers use materials so we can better design materials to support their changes in practice? Evanston Cent. Learn. Technol. Urban Sch. 4, 1–7.

Bruder, R. & Prescott, A. (2013) Research evidence on the benefits of IBL. ZDM. 45, 811–822.

Brune, M. (2010) The inquiry learning model as an approach to mathematics instruction. Idaho, ID: Boise State University; Master's Thesis.

Carlsson, S. (2003) Knowledge Managing and Knowledge Management Systems in Inter-Organizational Networks. Knowl. Process Manag. 10, 194-206.

Colburn, A. (2000) An Inquiry Primer. Sci. Scope 23: 42-44.

Conway, J. (2017) Effects of Guided Inquiry versus Lecture Instruction on Final Grade Distribution in a One-Semester Organic and Biochemistry Course. J. Chem. Educ. 91, 480-483.

Dantala, N. (2006) Effect of Computer-Assisted Instruction (CAI) package for individualized learning of history in the senior secondary school in Niger State. Akure: Federal University of Technology Master's Thesis.

Davies, D., Jindal-Snape, D., Collier, C., Digby, R., Hay, P. & Howe A. (2013) Creative learning environments in education-A systematic literature review. Think Ski Creat. 8, 80-91.

Domouctsidou, G. (2012) Teaching on the topic of proteins in the second grade of high school. NATSCI. 1, 69-75.

Doukeli, M. (2013) The utilization of virtual laboratory environments in teaching natural sciences in secondary education. Athens: University of Piraeus; Master's Thesis.

Driver, R. (1989) Students' conceptions and the learning of science. Int. J. Sci. Educ. 11, 481-490.

Driver, R., Squires, A., Rushworth, P. & Wood-Robinson V. (1999) Making sense of secondary science: Research into children's ideas. New York: Third Avenue.

Eisen, Y. & Stavy, R. (1993) How to make the learning of photosynthesis more relevant. Int. J. Sci. Educ. 15, 117-125.

Fakomogbon, M., Adetayo, O., Oyebode, A. & Enuma, M. (2014) Effect of computer assisted instructional package on the performance of students in mathematics in Ilorin Metropolis. Eur. Sci. J. 10, 196-206.

Ferguson, K. (2010) Inquiry based mathematics instruction versus traditional mathematics instruction: The effect on student understanding and comprehension in an eighth-grade pre-algebra classroom. Ohio, OH: Cedarville University; Master's Thesis.

Furtak, E.M., Seidel, T., Iverson, H. & Briggs, D.C. (2012) Experimental and quasi-experimental studies of inquiry-based science teaching. Rev. Educ. Res. 82, 300-329.

Gengarelly, L. & Abrams, E. (2009) Closing the Gap: Inquiry in Research and the Secondary Science Classroom. J. Sci. Educ. Tech. 18, 74-84.

Georgiou, M., Ziogka, K. & Galani, L. (2019) in G. Koutromanos & L. Galani, Eds. Critical approach of the Inquiry Learning Space (ILS) of the digital platform Go-Lab. (pp 329-338) Athens: Hellenic Scientific Association for Information & Communication Technologies in Education. ISBN 978-618-83186-4-9

Gökhan B. (2012) The effect of teaching learning strategies in an English lesson on student's achievement, attitudes and metacognitive awareness. J. Theoretic. Educ. Sci., 5, 49-71.

Hong, C., Hwang, Y., Liu, C., Ho, Y. & Chen, L. (2014) Using a "prediction-observation-explanation" inquiry model to enhance student interest and intention to continue science learning predicted by their Internet cognitive failure. Comput. Educ. 72, 110-120.

Idleman, B. (2012) Inquiry based learning in the chemistry classroom. Montana, MT: Montana University; Master's Thesis.

Jagannath, D. (2013) Effectiveness of computer assisted instruction in the development of study habits in relation to the gender, locality and socio-economic status of secondary school students. Int J Educ Psych Res. 2, 75-86.

Javeau, C. (2000) Investigating through questionnaires: the proper researcher's handbook. Athens: Dardanos.

de Jong, T., Sotiriou, S. & Gillet, D. (2014) Innovations in STEM education: The Go-LAB federation of online labs. Smart Learn. Environ. 1, 1-16.

Karamustafaoglu, S. (2010) Evaluating the science activities based on multiple intelligence theory. J. Turkish Sci. Educ. 7: 3-12.

Kici, D. (2012) Using technology in science education: A courseware to overcome misconceptions and learning difficulties about photosynthesis. Int. J. New Trends Art Sport Sci. Educ. 1, 30-40.

Lazonder, A. W. & Harmsen R. (2016) Meta-Analysis of Inquiry-Based Learning: Effects of Guidance. Rev. Educ. Res. 86: 681-718.

Lee, S. (2012) What Is Inquiry-Guided Learning? New Dir. Teach. Learn. 129: 5-14.

Malamitsa, K., Kokkotas, P, & Stamoulis, E. (2005). The use of aspects of History of Science in Teaching Science enhances the development of critical thinking - a proposal. In Eighth International History, Philosophy, Sociology & Science Teaching Conference. In Leeds, England, 879-894.

Marmaroti, P. & Galanopoulou, D. (2006) Pupils' Understanding of Photosynthesis: A questionnaire for the simultaneous assessment of all aspects. Int. J. Sci. Educ. 28, 383-403.

Matsaggouras, I. G. (2000) Team-based teaching of learning. Athens: Grigoris publications.

McComas, W. F. (2002) The Nature of Science in Science Education. Los Angeles: University of Southern California.

Moreland, J. L., Gramada, A. & Buzko, O. V. (2005) The Molecular Biology Toolkit (MBT): a modular platform for developing molecular visualization applications. BMC Bioinformatics, 6, 21.

Mulyana, S., Rusdi, R. & Sigit, D. (2018) The Effect of Guided Inquiry Learning Model and Scientific Performance on Student Learning Outcomes. Indonesian J. Sci. Educ. 2, 105-109.

National Research Council. National Science Education Standards. Washington, DC: The National Academies Press (1996).

OECD. PISA 2018 Results (Volume I): Excellence and Equity in Education, 1st ed. Paris: OECD Publishing; 2018.

Omokaadejo, L. (2015) Effects of inquiry method on academic performance of chemistry students in senior secondary schools in Kaduna state. Nairobi: Kenyatta University Master's Thesis.

Park, H., Khan, S. & Petrina, S. (2009) ICT in Science Education: A quasi-experimental study of achievement, attitudes toward science, and career aspirations of Korean middle school students. Int. J. Sci. Educ. 31, 993-1012.

Paxinou, E., Georgiou, M., Kakkos, V., Kalles, D., & Galani, L. (2022). Achieving educational goals in microscopy education by adopting virtual reality labs on top of face-to-face tutorials. Res. Sci. & Tech. Educ., 40(3), 320-339.

Pedaste, M., Mäeots, M., Siiman, L., de Jong, T., Riesen, S., Kamp, E., Manoli, C., Zacharia, Z. & Tsourlidaki E. (2015a) Phases of inquiry-based learning: Definitions and the inquiry cycle. Educ. Res. 14, 47-61.

Pedaste, M., Xenofontos, N., de Jong, T., Riesen, S., Kamp, E., Manoli, C. & Zacharia Z. (2015b) Identifying potential types of guidance for supporting student inquiry when using virtual and remote labs in science: A literature review. Educ. Technol. Res. Dev. 63, 257-302.

Ray A. & Beardsley, P. (2008) Overcoming Student Misconceptions about Photosynthesis: A Model- and Inquiry-Based Approach Using Aquatic Plants. Sci. Act. Classr. Proj. Curric. Ideas 45,13-22.

Robinson, R. (2017) Effectiveness of Computer Aided Instructions (CAI) on students' performance in basic electricity in technical colleges in rivers state of Nigeria. Int. J. Sci. Res., 5: 14-21.

Ryoo, K. & Linn, C. (2012) Can dynamic visualizations improve middle school students' understanding of energy in photosynthesis? J. Res. Sci. Teach. 49, 218-243.

Schmidt, H. & Jirstrand, M. (2006) Systems Biology Toolbox for MATLAB: a computational platform for research in systems biology. BMC Bioinformatics, 22, 514–515.

Schneegass, S., Oualil, Y. & Bulling, A. (2006) SkullConduct: Biometric User Identification on Eyewear Computers Using Bone Conduction Through the Skull. Proceedings of the SIGCHI conference on human factors in computing systems, https://doi.org/10.1145/2858036.2858152

Spronken-Smith, R., Angelo, T., Matthews, H., O'Steen, B. & Robertson J. (2007) How Effective is Inquiry-Based Learning in Linking Teaching and Research? France: UNESCO.

Stavy, R., Eisen, Y. & Yaakobi, D. (1987) How Students Aged 13-15 Understand Photosynthesis. Int. J. Sci. Educ. 9, 37-41.

Tamir, P. (1991) in BE Woolnough Practical science. Milton Keynes: Open University Press, pp. 742-775.

Tinio, L. (2003) ICT in education. Paper presented at UNDP for the Benefit of Participants to the World Summit on the Information Society. New York. ED 200-202.

Waheed, T. & Lucas, A. M. (1992) Understanding interrelated topics: photosynthesis at age 14+. J. BioL. Educ. 26, 193-199.

Wurst, C., Smarkola, C. & Gaffney, M.A. (2008) Ubiquitous Laptop Usage in Higher Education: Effects on Student Achievement, Student Satisfaction, and Constructivist Measures in Honors and Traditional Classrooms, Comput. Educ. 51, 1766-1783.

Yusuf, M. O. & Afolabi A. O. (2010) Effects of computer assisted instruction (CAI) on secondary school students' performance in biology. Turkish Online J. Educ. Technol. 9, 62-69.

Zhang, S. (2010) The study of effectiveness of Computer-Assisted Instruction versus Traditional Lecture in Probability and Statistics. ICEIT. 5, 360-363.

Ziogka, K., Georgiou, M., Galani, L. & Mavrikaki, E. (2019) "Cave explorers": Using Go-Lab digital scenarios to develop arguments based on geographical features." Eurogeo 2019 Conference, Paris, France, 14-15/3/2019 https://www.eurogeography.eu/wp-content/uploads/2019/03/2019-conference-progrmme-v2.pdf

Zion, M. & Mendelovici, R. (2012) Moving from structured to open inquiry: Challenges and limits, Sci. Educ. Int. 23: 383-399.

Zion M. & Sadeh, I. (2007) Curiosity and open inquiry learning. J. Biol. Educ. 41, 162-169.

Appendix A: List of Figure Captions

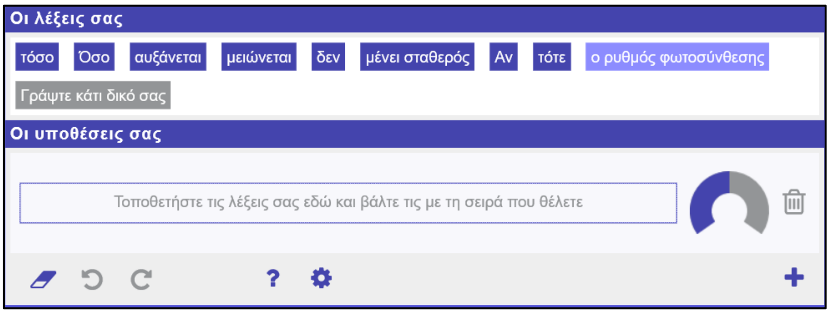

Figure 1: Hypothesis scratchpad
(Students have to build their hypothesis by dragging and dropping all/ some words of the frames in the preferable order, noting their certainty degree)

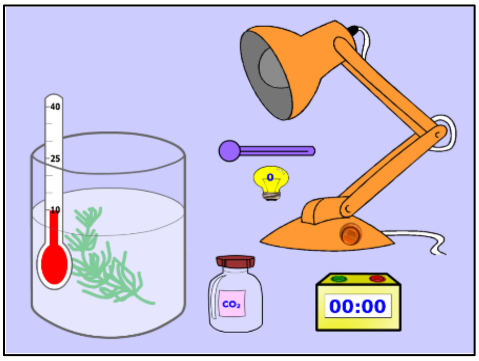

Figure 2: Photolab

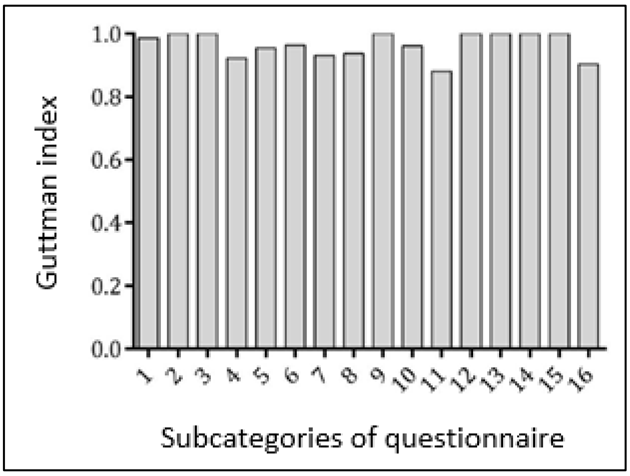

Figure 3: Guttman index

Appendix B

The post-test questionnaire's categories of questions (modified from Marmaroti & Galanopoulou, 2006).

The sub-categories were as follows:
1. Plants are fed from the soil.
2. Plants are fed from the water.
3. Plants are fed from carbon dioxide.
4. The role of sunlight.
5. The role of chlorophyll.
6. The place where photosynthesis occurs.
7. The time when photosynthesis occurs.
8. Reactants and products of photosynthesis.
9. Energy conversion.
10. The importance of photosynthesis.
11. Distinction of living beings into hetero- and autotrophic.
12. The rate of photosynthesis.
13. The dependence of photosynthesis rate upon available water levels.
14. The dependence of photosynthesis rate upon sunlight's brightness.
15. The dependence of photosynthesis rate upon temperature.
16. The dependence of photosynthesis rate upon carbon dioxide concentrations.