IADIS International Journal on WWW/Internet
Vol. 21, No. 2, pp. 33-48
ISSN: 1645-7641

CONTRIBUTION OF MOBILE DEVICES TO STUDENTS' CRITICAL THINKING & PROBLEM SOLVING SKILLS IN LABORATORY SETTINGS

Manolis Kousloglou, Eleni Petridou, Anastasios Molohidis
and Euripides Hatzikraniotis
Faculty of Physics, Aristotle University of Thessaloniki,
54124 Thessaloniki, Greece

ABSTRACT

The aim of this study is to evaluate the contribution of mobile devices to ninth-grade students' Critical thinking & Problem solving skills in laboratory settings. Students participated in a sequence of Microcomputer-based and mobile supported Laboratories, covering four different cognitive topics in Physics. Research instruments such as a reflective questionnaire, students' messages in a Viber group and a set of open-ended questions seem to enlighten the students' progress. Students' development of Critical thinking and Problem solving skills, over time in the Laboratory sequence, turns out by their way of manipulating, analysing, evaluating the experimental data and reflecting on the experimental procedures in the Viber group. Also, students' written responses to open-ended questions before and after the mobile-supported Labs revealed interesting data about their improvement.

KEYWORDS

Mobile Technology, Critical Thinking, Problem Solving, Greece, Secondary Education

1. INTRODUCTION

Critical thinking is a reasonable, reflective, responsible, and skilled thinking process that focuses on what to believe and do (Cavus & Uzunboylu, 2009). As a result of metacognition, students who can monitor and evaluate their own cognitive processes are more likely to exhibit high-quality thought. When students think critically, they assess the outcomes of their thought processes, such as the quality of a decision or the effectiveness of a Problem solving strategy. They also monitor their thought process by determining whether progress is being made towards an appropriate objective, ensuring accuracy, and deciding how to allocate time and mental effort (Halpern, 1998). The taxonomy for information processing skills (1956) created by Benjamin

Bloom and colleagues is one of the most frequently cited sources by educational practitioners for teaching and assessing higher-order thinking skills. "Comprehension" is at the bottom of Bloom's taxonomy, and "Evaluation" is at the summit. According to Lai (2011), the three greatest levels (analysis, synthesis, and evaluation) represent critical thinking. Critical thinking plays a role in the practice of Science in the following applications or processes: identifying and defining a scientific problem, locating suitable solutions to problems and evaluating their effectiveness, decision making, information gathering, question formulation, argumentation-defending ideas, discussion and debate, testing with care and rigor, rejecting-accepting a hypothesis (Santos, 2017). Problem solving in the context of education refers to the capacity of students to detect problems, obtain and evaluate pertinent information, develop solution strategies, propose alternative and viable solutions, solve problems and communicate the solutions (Hwang et al., 2018; OECD, 2005). Critical thinking and Problem solving skills, along with other skills belong to the 21st century skills that students must master to compete in the workforce of the future. Authors agree that problem solving or finding appropriate solutions for problems is one way in which Critical thinking and Science are linked (Santos, 2017).

Mobile learning can engage students in experiential and situated learning without location or time constraints and can enable them to continue learning activities begun inside or outside the classroom through contextual engagement and communication with them and/or teachers. In addition to supporting on-demand access to educational resources independent of students' commitments, mobile technology can facilitate the acquisition of new skills or knowledge (Sharples et al., 2009). Technology can improve students' higher-order cognitive skills, such as Critical thinking. As critical thinking is a crucial ability for modern students, teaching and learning tools must be able to promote its growth. Mobile technology may help to address this challenge. The virtual engagement of pupils in information retrieval alters both their cognitive processes and mental states. The ability of mobile technology to improve students' Critical thinking motivates them to become more developed and contemporary individuals (Ismail et al., 2016). By communicating at their own convenience via mobile technology, passive students may become more engaged in class. Mobile devices can enhance their experiences by promoting the reflection required for effective communication and critical thought. Through texting, phone, video, social networking, and other internet technologies, mobile learning may help promote students' critical reflection with others. Students are able to record their thoughts, observations, and activities on mobile devices for instant or later analysis and evaluation. This skill provides a routine and time for reflection, which may lead to a shift in viewpoint and the development of creative and critical thought (McCann & Camp, 2015). According to Greenlaw & Deloach (2003) online discussions can provide a natural framework for teaching Critical thinking because they can incorporate the best characteristics of traditional writing assignments and in-class discussions. They based this conclusion on several factors: first, online discussions shift the emphasis of the learning process, replacing the teacher's singular perspective with a variety of student perspectives. Second, this diversity of perspectives implicitly necessitates that readers compare and evaluate these perspectives. Thirdly, the asynchronous nature of online discussions allows participants time to consider what others have said and how they would like to respond. In contrast to class discussions, each participant has the opportunity to be heard in full. In addition, MacKnight (2000) stated that online discussions offer the opportunity for collaboration, increased participation in the learning process, reflection, peer tutoring, and monitoring of student learning as an extension of classroom learning. He suggested several measures to facilitate online discussions: (a) Maintain a focused discussion; (b) Keep the

discussion intellectually responsible; (c) Stimulate the discussion by asking probing questions that hold students accountable for their thinking; (d) Instill these questions in the minds of students; (e) Encourage full participation; (f) Periodically summarise what has or must be accomplished. Interventions in education that utilise these mobile capabilities go beyond information delivery to develop a platform that decreases the negative effects of time lag and promotes critical thought. Mobile technology permits the creation of new educational models (Fisher & Baird, 2006). Mobile technology is an effective learning medium that helps students to study anywhere and at any time, improves the learning process, and facilitates the mobility of equipment. It has been demonstrated that mobile technology facilitates student engagement in creative, collaborative, critical, and communicative learning activities in science education (Cavus & Uzunboylu, 2009; Saputra & Kuswanto, 2019). In addition, students can utilise mobile devices to improve their graphic representation and critical thinking skills (Saputra & Kuswanto, 2019).

The ability to collect physical experimental data in real-time and the data's immediate availability for analysis and presentation are key educational benefits of a wirelless MBL-system (Microcomputer-based Laboratories). Students can readily examine the effects of a large number of changes in experimental conditions in a short period of time due to the rapid collection and display of data. The MBL context adds capacity and flexibility that, in order to be utilized, necessitates a reconceptualization of the laboratory, providing students with more opportunities to investigate and learn through investigations. (Bernhard, 1998) Studies have shown that MBL experiments improve retention and develop graph analysis and interpretation abilities. It has been demonstrated that simultaneous graphical representation aids students in retaining the interpretive results in their long-term memory and clarifies the graph's salient features for a deeper understanding. In MBL experiments, peer learning is enhanced because students can use scientific symbols, diagrams, and graphs on the computer as "visual anchors" to stimulate comparisons and group discussion. (Rane, 2018). MBL can provide science students with unprecedented ability to investigate, measure, and learn from the physical world while leaving them in charge of their own education. Using the immediate environment as a laboratory and working in an environment where they can comprehend and manipulate data derived from the tangible world, students in an introductory science course can form and test hypotheses with the aid of these tools. Therefore, MBL can provide students with an opportunity to investigate their 'common sense' scientific understandings and attach them to a more formal framework (Thornton, 1987). Graphs are useful in science as a means for critical-response, an instrument for critically evaluating data; therefore, it is suggested that scientifically literate individuals can utilise graphs to evaluate data-based arguments and claims (Glazer, 2011). Students who can utilise various representations to comprehend a scientific concept will have a simpler time grasping the concept. This capacity is referred to as multiple representations. In order to complete cognitive processes, limit the possibility of misinterpretation, and deepen understanding of a situation, a student should have this ability in science learning (Ainsworth et al., 1997). Science education emphasises the process of problem solving that requires scientific knowledge to conduct an investigation or experiment. While multiple representations serve to complete and investigate concepts in depth, as well as anticipate misinterpretation of the data or information obtained, they also serve to prevent such misinterpretation. Therefore, it teaches them to always think critically. The science learning model that employs discovery learning followed by multiple representations is anticipated to be able to meet and facilitate the needs of learning descriptive, procedural, declarative, and abstract science. Students who are able to learn

science in this context will significantly increase their concept comprehension, science process skills, and critical thinking (Syahmel & Jumadi, 2019).

However, for learning to be successful in improving students' 21st century skills, teachers should not only use the right media but must also apply the right learning approach (Eveline, 2019). Mobile technology alone cannot guarantee the efficacy of learning; rather, the success of learning is partly decided by a mobile-based learning process. If mobile technology is used simply to memorize information searches and teachers fail to establish an appropriate teaching method to be used in conjunction with the technology to enhance students' critical thinking, the potential of the technology is lost. Teachers must thus create a class that incorporates mobile technology in a way that not only attracts and motivates students, but also leads to a more meaningful learning experience that improves students' higher-order thinking, particularly their critical thinking (Ismail et al., 2016). In addition, the integration of technology and well-designed educational activities makes the transfer of knowledge and skills across settings and life transitions feasible (McCann & Camp, 2015).

This study claims that well-designed, technology-enabled learning environments provide valuable chances for reflection and critical thinking. The chosen instructional strategy is an inquiry-based approach, which shifts the emphasis of science education from traditional memorization of facts and concepts in separate specific disciplines to inquiry-based learning in which students are actively engaged in using both science processes and critical thinking skills as they seek answers (Zacharia, 2003). Not only does requiring students to undertake original research strengthen their critical thinking in respect to their own work, but it also increases research outputs generally. Research experience boosts students' awareness of how evidence may be used to demonstrate a certain opinion and improves their comprehension of newspaper and website material. Instead of accepting results at face value, they submit questions for data analysis, which significantly increases their engagement in the learning process (Wyatt, 2005).

The importance of investigating the development of Critical thinking and Problem solving skills through mobile-supported Labs stems from the correlation between the findings and classroom practices. Critical thinking and Problem solving skills are usually assessed by using a pretest/post-test quasi-experimental design (Zheng et al., 2016), by using the independent–sample t–test in a large sample (Lai & Hwang, 2014), by administering semi-structured interviews, by doing class observation or a combination of these methods (Agustina et al., 2022). Surveys address either the dispositional dimension of critical thinking (ex. the California Critical Thinking Disposition Inventory – CCTDI, e.g. Unlu & Dokme, 2017), or the actual skills dimension (ex. the California Critical Thinking Skills Test – CCTST, e.g. Stephenson et al., 2019). Although worldwide research has been undertaken on the relationship between mobile technology and critical thinking, the cultural background of each country may impact the findings. In addition, in Greece mobile learning is an underexplored topic and the development of higher-order thinking skills is weak. Consequently, the present research, which was done in Greece, adds to worldwide research, and the findings are anticipated to have significance for researchers and school policymakers.

In this work, we investigate the contribution of MBL and mobile in laboratory settings to the development of students' Critical thinking and Problem solving skills. The research question was: *To what extend the use of MBL and mobile in a laboratory setting contributes to the development of students' Critical thinking & Problem solving skills and how is this evaluated?*.

2. METHOD

2.1 The Sample

This study was conducted in a Junior high school in Kavala, Greece, during the second semester of the academic year 2021-22. The sample consisted of 10 ninth graders (15 years old) who willingly participated in the school's science club. The science club members met once a week after school hours. One of the authors of this study, who also taught science to the pupils, formed this group. Four females and six males with high Physics grades participated in a mobile-supported Lab sequence. The students were skilled with their smart phones but had never been engaged before in mobile learning activities.

2.2 Design of the Lab Sequence

The Lab sequence consists of 4 topics, namely Hooke's Law, Linear Oscillator, Pendulum and Friction. Each topic has 4 experimental (Lab) sessions: familiarize, explore, extend and reflect. Each Lab session lasts one week. Thus, the whole Lab sequence lasted 16 weeks. Each Lab has three phases (pre-Lab, in-Lab, post-Lab). The unfolded structure of the Lab sequence is depicted in Figure 1.

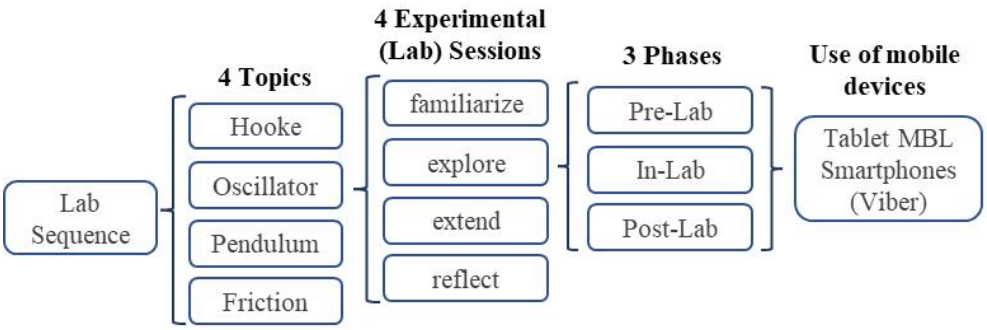

Figure 1. The unfolded structure of the Lab sequence

A short description of the 4 Lab sessions of each topic is as below:

- *familiarize:* Basic theoretical notions are discussed. The students become familiarised with the measurement setup by studying the capabilities of the wireless sensors and the affordances of the accompanying software, they do tests, discuss and exchange ideas about their use in the Sciences laboratory.
- *explore:* The basic parameters that affect the experimental result are investigated (ex. spring stiffness, hanging weight).
- *extend*: An exploration of extended features takes place (ex. 2 springs in series/parallel).
- *reflect*: The students reflect on the concepts, the experimental procedures, the way that evidence can be drawn from graphs, the reliability of the measurements, the communication of the findings etc.

A short description of each phase in each Lab session is as below:

- *pre-Lab*: A captivating scenario is provided to pique the students' curiosity, address a learning challenge, and spark conversation regarding the inquiry procedure. As an example, in the study of friction: *On a chair in our home were numerous items, including a cup, a booklet-calorie counter, a kettle, and even our mobile phone! When we lifted the chair from one side so that our father could remove the carpet underneath, some items slipped and fell to the floor*. The students fill an Experiment Design Plan sheet. Questions are asked to promote critical thinking, such as "What are we investigating?", "What is our hypothesis?", "How will we construct an experiment?", and "How will we test our hypothesis?".
- *in-Lab*: The experiment is carried out using wireless sensors and tablets as Microcomputer-based Laboratories (MBL). The students monitor the evolution of relative dynamic diagram representations in their smartphones/tablets via shared session affordance of SPARKvue software. The monitoring takes place in-class or from home for the students who are unable to physically attend the lab owing to an unusual circumstance, such as illness. Students working collaboratively, discuss the results within their group, and present them to the entire class and to the teacher in plenary.
- *post-Lab*: Analysis of the results takes place and a reflective procedure about the whole Lab sequence is applied. The students complete a Reflective Experiment Design Sheet. Indicative questions for promoting critical thinking are “What did we investigate?”, “What was our hypothesis?”, “How was our hypothesis verified?". Students also reflect on the data provided from graphs.

2.3 Implementation of the Lab Sequence Utilizing Mobile Devices

Nowadays, the extensive use of mobile devices has replaced the typical Laboratory equipment in a modern classroom. Actions that in the past years were typically carried out by a computer, are now being performed by a tablet. The use of wireless sensors has eliminated the need for the interface through which older days wired sensors were connected to the computer.

In our Lab sequence, we used both conventional laboratory equipment (springs, weights, bases, clamps, etc.) and mobile technologies (PASCO Force Acceleration Sensors and SPARKvue software on school tablets). Wireless Force Acceleration Sensors monitor force, acceleration, and rotational velocity. These devices link with PASCO SPARKvue suite software through bluetooth for data logging on tablets/smartphones (SPARKvue, 2014) and visualize data in many ways (graphs, tables, numeric indicators, etc). Students can monitor the evolution of the experiment on their smartphone screen through the *Shared Session* affordance, which also saves the experiment individually so that the data be analyzed afterward. Figure 2 illustrates a smartphone display during the oscillation experiment. Three student groups are connected to a shared session to obtain real-time data and its accompanying graph. One student, who is not physically present in the school laboratory and is connected from home, has the opportunity to observe the experiment, the data-logging diagram and to acquire the experimental data.

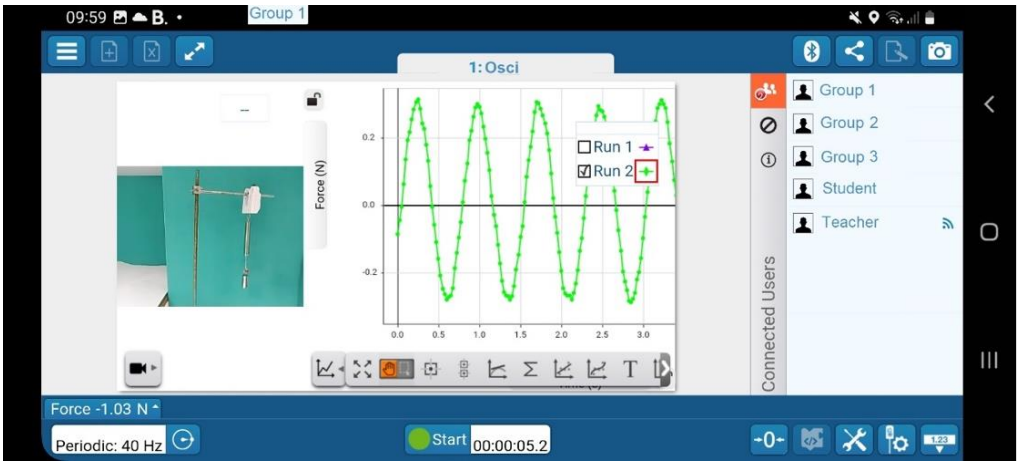

Figure 2. PASCO SparkVue datalogging software shared session

Students also used their smartphones for both student-to-student and student-to-teacher communication and reflection on the experimental procedure. This was accomplished by forming a Viber group, which provided students with an extra channel for information, communication, and cooperation via their smartphones, also outside the classroom environment. A brief description of the utilization of the mobile devices in each phase of the Lab sessions, as depicted in Figure 1, is as below:

- *pre-Lab phases:* The Viber group was employed for discussions on the science club's procedures and the planning and resolution of relevant questions. Thus, during the Labs the participants had more time to focus on issues related to the experimental process. In several circumstances of student absence, links to distance learning platforms (Zoom/Webex) and reports to be completed were distributed through the group to facilitate the active participation of absent students. Students considered the capabilities of the wireless sensors and the affordances of their software when designing the experiments.
- *in-Lab phases:* After having completed individually the Experiment Design Plan sheet, the students discussed, among other things, how they planned to utilise the portable digital devices of the laboratory, how they planned to inject them into the experiment, and how they planned to analyse the data they collected. (graphs, calculation of physical quantities etc.). Various options were discussed, and the best one was ultimately chosen. During the experiment, the tablets were utilised as MBLs for diagram generation and study. Concerning the diagrams resulting from the experimental data, contentious debates between the students were held. In addition, share session affordance and/or a tablet camera were utilised for students' active involvement in distant experiments using their mobile phones.
- *post-Lab phases*: The Viber group was used to settle questions regarding student assignments or charts to be processed, to transmit diagnostics to be filled as reflective, and to resolve questions. In addition, methods of disseminating the findings to the larger scientific school community were discussed. In addition, the students' mobile phones served as MBLs, as the data and diagrams from the experiments were recorded on them for additional examination at home. Lastly, cell phones were utilised to capture the procedure for use in presentations and conferences.

Students worked in groups of three or four and were supported by worksheets. The four topics of the Lab sequence were structured using the same inquiry-based learning framework according to Pedaste et al. (2015). In each Lab, the students were oriented through a story based on everyday life, developed testable questions, formulated hypotheses about the probable answers, designed and conducted experiments to test their hypotheses, analyzed and evaluated the data, drew conclusions, and communicated their findings to the class, receiving feedback and review from their classmates. Although reflection occurred throughout the whole procedure, students reflected on the entire Lab during the final reflect session. They also completed a Reflection Report at home during the entirety of the Lab session using their smartphones.

2.4 The Measuring Instruments

In order to evaluate students' Critical thinking and Problem solving skills a reflecting essay/questionnaire was given to students after each topic of the Laboratory process, recordings of students' written dialogues on the Viber group were analysed and a set of open-ended questions posed to students before and after the completion of the Laboratory sequence were evaluated.

The reflecting essay/questionnaire was created and administered after the completion of each topic in order to highlight the relation between the development of students' Critical thinking & Problem solving skills, and the use of MBL. Students answered two questions concerning the analysis of the collected data (in-Lab phase) and two questions concerning the evaluation of the experimental process (post-Lab phase). The questions can be seen in Appendix A. A three-level analysis framework (0, 1, 2) was created to evaluate the students' responses as it is seen in Table 1.

Table 1. Three level analysis framework

	Level 0	Level 1	Level 2
Analysis of the data (In Lab)	The student does not answer one of the two questions at all	The student answers both questions, but incompletely in one of them	The student answers both questions completely
Evaluation of the experimental process (Post Lab)	The student does not answer any of the questions or answers one of them without justification	The student answers both questions, but incompletely	The student answers both questions completely

As it is seen in Table 1, regarding the analysis of data, when students didn't answer one of the two questions, their answers were scored with 0. If one of the questions was answered incompletely, that means the students weren't referring to the manipulation of the variables by recognizing the dependent and the independent one or if they weren't interpreting the graph, the answers were scored with 1. Finally, if in both questions students were answering completely, their answers were scored with 2. Regarding the evaluation of the experimental process, when students didn't answer any of the questions or if they answered one of them without justification, their answers were scored with 0. Students' answers that didn't consider the measurement errors

or didn't include specific suggestions for improving the experimental setup were scored with 1, while the complete students' answers were scored with 2.

Recordings of students' written dialogues on the Viber platform were evaluated to detect critical thinking and problem solving characteristics. Ethical issues were taken into account according to the new General Data Protection Regulation. The questionnaires were anonymous. Both the school board and the students were notified that all data gathered from the surveys and the Viber group will be utilised only for research purposes.

Moreover, before and after completing the Lab Sequence, students were required to answer a set of open-ended questions forming the assessment tool. Appendix B's open-ended questions were based on the topics of the questionnaire created by Hwang et al. (2018), in an effort to undertake a more in-depth analysis. The content of the students' free-form written responses was analysed by two authors of this research. Inter-rater reliability of 0.90 was achieved when two researchers separately categorized pre- and post-test student responses and then engaged in a lengthy discussion to resolve any inconsistencies.

3. RESULTS AND DISCUSSION

3.1 Analysis of the In- and Post-Lab MBL Impact

The results of the essay/questionnaire administered after the in- and post-Lab phase, in each topic, reflect the students' progress concerning the analysis of the data and the evaluation of the experimental process with the MBL. These two issues (data analysis and evaluation of the experimental process) as require critical thinking and problem solving skills, highlight the students' progress on them. The blue line in Figure 3 shows the students' progress to analyze and interpret the experimental data by defining the dependent and independent variable of the experiment and by extracting the relation between the physical quantities represented by the graph. The orange line, in Figure 3, refers to the students' progress to evaluate the experimental process by assessing the data errors in measurements and by suggesting possible improvements to the experimental setup. The students' progress is calculated from the average score gained following the three-level analysis framework, described in the methodology section above, in each topic (Hooke, Oscillator, Pendulum, Friction).

In terms of data manipulation and analysis, a considerable improvement of the students is seen after their participation in the four Lab topics. The students started with a low score (0.46) after the first Lab topic (Hooke's Law), while after finishing the last Lab topic (Friction), they achieved a high score (1.62).

Both the content and evolution of students' responses are of considerable interest. The low score after the first Lab topic results from students' answers which do not include the manipulation of the experimental variables and the interpretation of the graph. For example, student S3 wrote, "*I saw the data on the screen of my tablet and understood how the phenomenon evolved*." Accordingly, student S5 responded, "*I tabulated the data in SPARKvue and converted it to a graph*." Another representative answer of student S9 is, "*As we added weights, I observed on my tablet how much the spring stretched. In addition, I deduced from the weight - spring elongation graph that spring elongation is proportional to weight".*

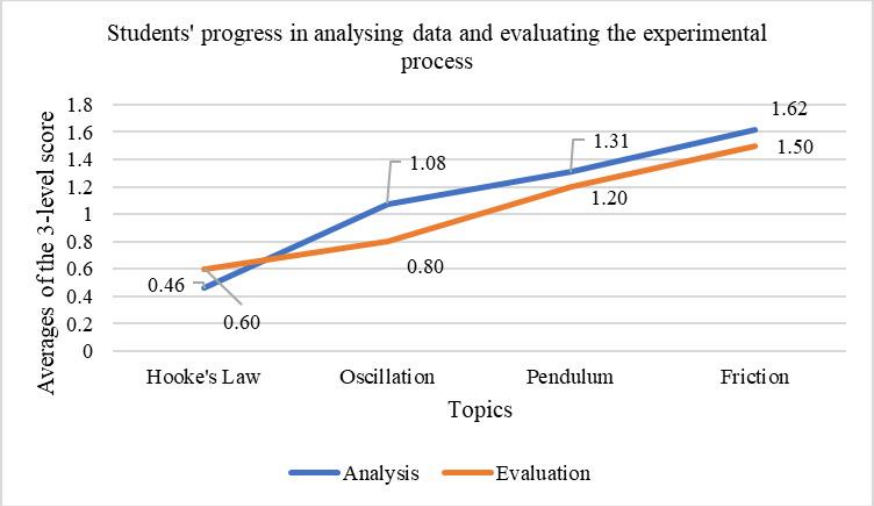

Figure 3. PASCO SparkVue datalogging software shared session

After the fourth Lab topic (Friction), students' answers included reflective observations on the graphs and they recognized the relationship between the physical quantities. Representative answers of the same students follow. Student S3 wrote "*During the experiment, I observed the box's behaviour, i.e., whether it was stationary or not, as well as the force-time graph's evolution. Just when that box started to move, the graph was thrown off! We repeated the experiment with various weights on the box and input the data into a SPARKvue table. The Weight - Friction graph displayed a diagonal line, indicating that the quantities are proportional!*" Accordingly, student S5 wrote, "*Initially, I observed a perturbation in the graph on my tablet, just at the moment that the box moved. We discussed in our group why this may have occurred. Concerning the collected data, the graph demonstrated that the quantities are proportional. Of course, we discussed the reason why the graph was not a perfect line*". Student S9 made the following observation: "*Before tabulating our measurements, we deliberated as a group what we would observe and what would be the result. We did it as a game, and I won by predicting that the points would not be precisely on a straight line due to experimental errors, while the others argued that a straight line would be observed"*.

Regarding the evaluation of the experimental process and the specific questions, "How much do we trust the data-driven conclusions? How could the experimental procedure be improved?", the students' improvement among the Lab topics, is seen in Figure 3. The students' initial score (0.60) after the first Lab topic was low. However, following the completion of the whole procedure, they obtained a score of 1.50. Exemplary student responses prior to the Lab sequence include: S6 "*since we used electronic sensors, we trust the results*" and S10 "*we trust the results, but there will undoubtedly be measurement errors. However, I do not believe that these errors are substantial enough to influence the outcome*", and S12 "*I would enhance the process by taking more measurements, as it is simple to do so with tablets and sensors*". S6's response to the question following the Lab sequence was, "*Although electronic devices are extremely reliable, students make mistakes. When the teacher permitted, we repeated the experiment. The procedure would be improved if we had additional sensors and conducted all of the experiments*". "*I liked the fact that I could see the real experiment and the graph at the same*

time, and I could pinpoint exactly when the box began to move. I do not know if there was a delay in time. I'd also like to conduct the experiment with a dynamometer to compare the results!", wrote S10. S12 stated, "*The results were accurate because we were able to focus in and measure precisely on the SPARKvue graph. We could also do that at home, without duress. It would be very useful for us to hear a sound when the box began to move*".

From students' answers it is seen the development of Critical thinking and problem solving skills, as they think about the possible evolution of an experiment and they compare their predictions with the experimental data. Moreover, students cope with the challenging process of deriving the relationship between physical quantities from a graph and proposing improvements to an experimental setup.

3.2 Analysis of the Post-Lab Viber Communication

The Post-Lab Viber communication was carried out with text messages. Apart from the messages of social type ("hello", "how are you", etc.) a total of 1046 messages referring directly to the Lab activities were exchanged in the Viber group, during the four-month operation of the science club. Viber messages were classified into four categories depending on the content of their discussions: (a) procedural issues, (b) Lab homework, (c) Connectivity issues and (d) Discussion for motivation purposes. 48% of the total 1046 messages refer to Procedural issues, 36% to Lab homework, 3% to connectivity issues and 13% is devoted to motivation purposes. *Procedural issues* concern discussions of a procedural nature pertaining to the running of the science club, including changes to the meeting schedule, absences, student assignments etc. *Connectivity issues*, such as sending links to distance learning platforms for students that could not participate face to face in the Labs. *Discussion for motivation purposes* refers to messages between the teacher and the students to cultivate a pleasant context, enhance active participation, engagement and encouragement. Finally, *Lab homework messages* concern reflective debate between students for the completion of the assignments in the post-lab phase of each Lab. Students in their messages look for evidence in the graphs, consider other interpretations in data analysis, participate in reflective discussions about the experiments and come up with solutions in challenging situations in the experimental setups. Analysis of the Viber-message threads has shown that students seem to examine the "big-picture", avoid emotional reasoning or oversimplifications, question the conclusions and understand the problem they are dealing with. Such items are indicative of the evolution of students' Critical thinking & Problem solving skills.

Figure 4 depicts the number of messages per topic for each of the four categories: (a) Procedural issues (b) Lab homework, (c) Connectivity issues, and (d) Discussion for motivation purposes. As can be observed, during the four topics of the Lab sequence, a significant number of messages dealt with issues pertaining to Critical thinking and Problem solving skills. By establishing a Viber group, digital mobile devices were used by students to communicate/argue about methods and scientific practices without regard to space or time limitations. The reflective processes through the possibility of further study of dialogues, but also of the distributed material at any time via their mobile devices, and the students' continuous collaboration in the Viber group may have aided in the development of their Critical thinking and Problem solving skills.

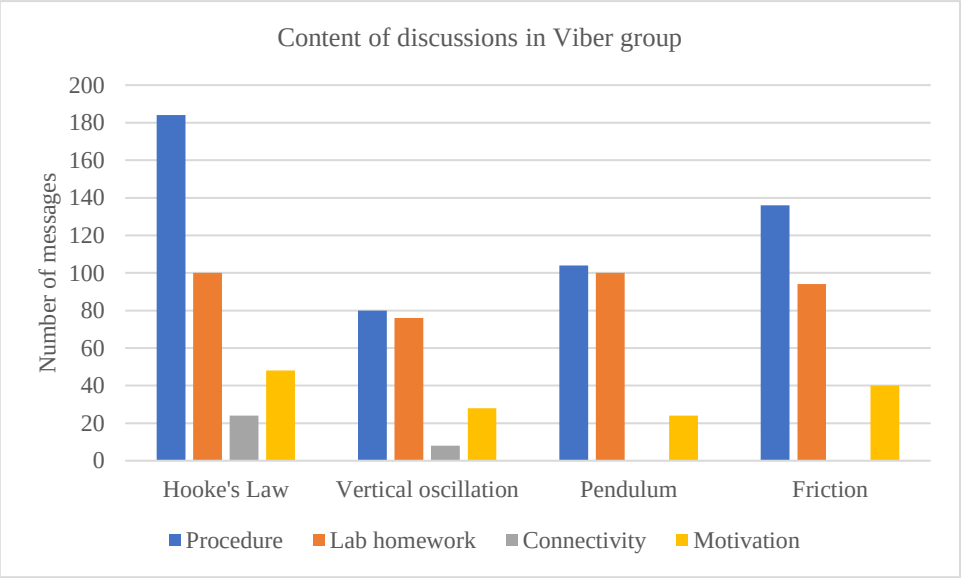

Figure 4. Classification of messages in Viber group

The deep thinking through the study/explanation of the diagrams that MBL created in real time, as well as their storage in the mobile devices of the students for further study and analysis at home, in combination with the reflective processes that inquiry-based learning strategy required (Experiment and Reflective Design Plan sheets) may have contributed to the promotion of students' Critical thinking & Problem solving skills. In addition, the shared session affordance of SPARKvue enabled the involvement of students who were unable to attend some group sessions in person, keeping them involved throughout the whole Lab sequence.

3.3 Analysis of the Students' Answers to the Open-Ended Questions

In order to explore in depth the development of Critical thinking and Problem solving skills, students (S1 to S10) were asked open-ended questions before and after the Lab sequence (Appendix B). Firstly, students were asked to answer if they considered it essential to make pauses and think over the experimental process and if their pauses were mandatory, spontaneously or consciously. Table 2 gathers the students' answers.

Table 2. Reflecting/monitoring, evaluating processes of thought

	Pauses for Critical thinking			
	No pauses	Mandatory	Spontaneously	Consciously
PRE	5	2	1	2
POST	0	1	4	5

The evolution of students' conceptions of critical thinking skills over time is seen in Table 2. As can be seen, at the beginning of the procedure, only three students reported pausing to reflect during the experiment (1 spontaneously and 2 consciously), whereas half of the students

did not pause at all. The students' selection of the word "mandatory stop" implies the end of their job and not an opportunity for thought or observation. Following the Lab sequence, nine out of ten students declared that they either intentionally or unintentionally, reported pausing to analyse and reflect on the process. Representative students' answers are as follows: S1 "*Occasionally, I pause to decide if what I'm doing is correct or incorrect*" or S5 "*If I do pause, I do it intentionally to comprehend the subject I am researching*".

In the second and third questions students were asked to define what "alternative options" meant to them, while solving a problem and what could make them strong complex problem solvers. In Table 3 students' answers were gathered.

Table 3. Categorizing students' written answers about Critical thinking & Problem solving

	Proposing alternative and viable solutions	Detecting and understanding the problem
PRE	5	4
POST	8	8

Prior to the Lab sequence, only five out of ten students mentioned alternative viable answers to a Problem. However, following the Lab sequence, eight out of ten students identified alternative viable solutions as a characteristic of Critical thinking and Problem solving skills. An exemplary student response is: S5 "*For me, alternative solutions involve exploring all potential answers to a Problem while concurrently confirming my results*". Prior to the Lab sequence, no student said that appraisal of a claim or piece of information, analysis of a difficult circumstance, and synthesis are essential factors for finding answers, however, four students did so thereafter. Indicatively, S4 stated, "*I always attempt to consider a suggestion or piece of information that a groupmate provides*", and S8 mentioned that "*each time I attempt to assemble the data I acquire, it is like putting together a puzzle*". Indicative students' answers to the question "What makes you a strong problem solver?" after the Lab sequence are S2 "*I am able to tackle problems because I thoroughly study, comprehend, and then effectively solve them*" or S9 "*My ability to utilise prior knowledge acquired from addressing earlier challenges enables me to solve the problems I meet*".

4. CONCLUSION

This study aimed at examining the contribution of mobile and MBL devices to the development of Critical thinking & Problem solving skills in laboratory settings. The students' answers to the reflective essay/questionnaire after the in- and post-Lab phase, in each topic, reflect their progress concerning the analysis of the data and the evaluation of the experimental process with the MBL. Also, students' participation in discussions through their smartphones, before and after the Lab experimentation in the class, gave them the opportunity to develop their Critical thinking & Problem solving skills. The student's participation in the Viber group, during the pre-phase of the Lab sessions, allowed for reflection on the scenario and the possible ways of controlling their hypotheses. The captured graphs of the experimental data, saved on students' smartphones, were the starting point for each of them to discuss and reflect on the results through the Viber group even outside the Lab class in the school. This fact also ensured the continuous involvement of the students in the reflection both before and after the execution of the

experiments. An interesting result is students' reflection on the manipulation of the experimental data and the interpretation of the graphs over time. It is obvious the progress of their ability to analyze and interpret the experimental data by defining the dependent and independent variable of the experiment and by extracting the relation between the physical quantities represented by the graph. Remarkable, also, is students' progress to evaluate the experimental process by assessing the data errors in measurements and by suggesting possible improvements to the experimental setup.

This study's findings represent a micro-level scenario and can contribute to the expansion of the literature on the subject of mobile learning, which has not been systematically incorporated into the Greece education system's curriculum. This is an ongoing project. Future goals include the investigation of what extent mobile-supported Labs promote other 21st century skills, such as creativity, collaboration, and communication.

REFERENCES

Agustina, N., Mayuni, I., Iskandar, I., & Ratminingsih, N. M. (2022). Mobile learning application: Infusing critical thinking in the EFL classroom. *Studies in English Language and Education*, *9*(2), 16. https://doi.org/10.24815/siele.v9i2.23476

Ainsworth, S. E., Bibby, P. A., & Wood, D. J. (1997). Information technology and multiple representations: New opportunities–new problems. *Journal of Information Technology for Teacher Education*, *6*(1), 93-105. https://doi.org/10.1080/14759399700200006

Bernhard, J. (1998). Hands-On Experiments in Advanced Mechanics Courses. *Proceedings of the ICPE/GIREP International Conference "Hands-on Experiments in Physics Education",* Duisburg, Germany, 23–28 August, 1998.

Bloom Benjamin (Ed.) (1956). *Taxonomy of educational objectives: The classification of educational goals. Handbook 1, Cognitive Domain*. New York, NY: David McKay.

Cavus, N., & Uzunboylu, H. (2009). Improving critical thinking skills in mobile learning. *Procedia-Social and Behavioral Sciences*, *1*(1), 434-438. https://doi.org/10.1016/j.sbspro.2009.01.078

Eveline, E., Suparno, S., Ardiyati, T. K., & Dasilva, B. E. (2019). Development of Interactive Physics Mobile Learning Media for Enhancing Students' HOTS in Impulse and Momentum with Scaffolding Learning Approach. *Jurnal Penelitian & Pengembangan Pendidikan Fisika*, 5(2), 123–132

https://doi.org/10.21009/1.05207

Fisher, M., & Baird, D. E. (2006). Making mLearning work: utilizing mobile technology for active exploration, collaboration, assessment, and reflection in higher education. *Journal of Educational Technology Systems*, *35*(1), 3-30. https://doi.org/10.2190/4T10-RX04-113N-8858

Glazer, N. (2011). Challenges with graph interpretation: A review of the literature. *Studies in science education*, *47*(2), 183-210.

Greenlaw, S. A., & DeLoach, S. B. (2003). Teaching critical thinking with electronic discussion. *The Journal of Economic Education*, *34*(1), 36-52.

Halpern, D. F. (1998). *Teaching critical thinking for transfer across domains: Disposition, skills, structure training, and metacognitive monitoring. American Psychologist, 53*(4), *449–455.* https://doi.org/10.1037/0003-066x.53.4.449

Hwang, G. J., Lai, C. L., Liang, J. C., Chu, H. C., & Tsai, C. C. (2018). A long-term experiment to investigate the relationships between high school students' perceptions of mobile learning and peer interaction and higher-order thinking tendencies. *Educational Technology Research and Development, 66*(1), 75-93.https://doi.org/10.1007/s11423-017-9540-3

Ismail, N. S., Harun, J., Salleh, S., & Zakaria, M. A. Z. M. (2016). Supporting students' critical thinking with a mobile learning environment: a meta-analysis. In *10th International Technology, Education and Development Conference. Valence, Spain: INTED2016 Proceedings* (pp. 3746-55). https://doi.org/10.21125/inted.2016.1899

Lai, E. R. (2011). Critical thinking: A literature review. *Pearson's Research Reports*

Lai, C. L., & Hwang, G. J. (2014). Effects of mobile learning time on students' conception of collaboration, communication, complex problem–solving, meta–cognitive awareness and creativity. *International Journal of Mobile Learning and Organisation*, *8*(3-4), 276-291. https://doi.org/10.1504/IJMLO.2014.067029

McCann, S., & Camp Pendleton, C. A. (2015). Higher order mLearning: Critical thinking in mobile learning. *MODSIM World*, *208*, 1-11.

MacKnight, C. B. (2000). Teaching critical thinking through online discussions. *Educause Quarterly*, *23* (4), 38-41.

OECD. (2005). *PISA 2003 Technical Report*. Paris: OECD

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. (2015). Phases of Inquiry-Based Learning: Definitions and the Inquiry Cycle. *Educational Research Review, 14*, 47–61. https://doi.org/10.1016/j.edurev.2015.02.003

Rane, L. V. (2018). *Microcomputer Based Laboratory – An effective instructional tool : A review*. *5*(1), 530–537.

Santos, L. F. (2017). The role of critical thinking in science education. *Online Submission*, *8*(20), 160-173.

Saputra, M., & Kuswanto, H. (2019). The Effectiveness of Physics Mobile Learning (PML) with HomboBatu Theme to Improve the Ability of Diagram Representation and Critical Thinking of Senior High School Students. *International Journal of Instruction*, *12*(2), 471-490. https://doi.org/10.29333/iji.2019.12230a

Sharples, M., Arnedillo-Sánchez, I., Milrad, M., & Vavoula, G. (2009). Mobile learning. In: Balacheff, N., Ludvigsen, S., de Jong, T., Lazonder, A., Barnes, S. (eds). *Technology-enhanced learning* (pp. 233-249). Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-9827-7_14

SPARKvue (4.7.1.8). (2014). [Mobile app]. PASCO.

Stephenson, N. S., Miller, I. R., & Sadler-Mcknight, N. P. (2019). Impact of peer-led team learning and the science writing and workshop template on the critical thinking skills of first-year chemistry students. Journal of Chemical Education, 96(5), 841–849. https://doi.org/10.1021/acs.jchemed.8b00836

Syahmel, S., & Jumadi, J. (2019). Discovery Learning using Multiple Representation model for enhancing scientific processing and critical thinking skills of the students. *Jurnal Inovasi Pendidikan IPA, 5*(2), 180-194.

Thornton, R. K. (1987). Tools for scientific thinking-microcomputer-based laboratories for physics teaching. *Physics Education, 22* (4), 230.

Unlu, Z. K., & Dokme, I. (2017). Science teacher candidates' epistemological beliefs and critical thinking disposition. *Eurasian Journal of Educational Research, 72*, 203-220.

https://dergipark.org.tr/en/pub/ejer/issue/42492/511913

Wyatt, S. (2005). Extending inquiry-based learning to include original experimentation. *The Journal of General Education*, *54*(2), 83-89. https://www.jstor.org/stable/27798010

Zacharia, Z. (2003). Beliefs, attitudes, and intentions of science teachers regarding the educational use of computer simulations and inquiry-based experiments in physics. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *40*(8), 792-823. https://doi.org/10.1002/tea.10112

Zheng, L., Chen, N. S., Li, X., & Huang, R. (2016). The impact of a two-round, mobile peer assessment on learning achievements, critical thinking skills, and meta-cognitive awareness. *International Journal of Mobile Learning and Organisation, 10* (4), 292-306. https://doi.org/10.1504/IJMLO.2016.079503

APPENDIX A: REFLECTING ESSAY/QUESTIONNAIRE

Analysis

- How did you manage your research data?
- Did you find a relationship between the physical quantity you measured (dependent variable) and the quantity you changed in each case (independent variable)? How did you find that out?

Evaluation

- To what extent can you trust the conclusions drawn from the data?
- How could you improve the experimental process?

APPENDIX B: OPEN-ENDED QUESTIONS

- Do you consider it essential to make pauses and think-over, when you work in Lab or for homework? Please explain.
- What is the meaning of “alternative solutions” to you?
- What makes you a “strong Problem solver”?