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The impact of an online physics lab on university students' self-efficacy and understanding of thermal concepts during COVID-19 pandemic

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ABSTRACT

COVID-19 has caused widespread disruption, necessitating tough decisions for global economy and services, including one of the central social pillars, education. As in the rest of the world, Greek universities transformed and adapted their educational services to continue to operate during the pandemic. This article presents how a series of a physics laboratory work for thermal concepts was conducted to evaluate its effectiveness on students' understanding and its impact on their self-efficacy beliefs. The results showed that the post-test performance on students' understanding of thermal concepts and their self-efficacy beliefs levels toward physics teaching were higher than pre-test performance but still moderate. A critical challenge was to maintain the experiential consistency with the in-person laboratory classes of all the previous academic years and the promotion of group work of students.

Keywords: experiments, thermal concepts, self-efficacy, students

INTRODUCTION

Physics constitutes a fundamentally experimental science making laboratory work an essential component of physics learning (Feynman et al., 1963; Hofstein & Lunetta, 2004; Ojediran et al., 2014), thus an integral part of the physics curriculum, providing the opportunity for students to engage in scientific inquiry (Clough, 2002; Crouch & Geller, 2023). The provided laboratory should aim to work to meet the needs of a diverse student population, engaging them in authentic scientific experience and practices centering on constructing physics knowledge, modeling, designing physics experiments, developing technical and practical laboratory skills, analyzing and visualizing data, and communicating physics (American Physical Society, 2016). According to the National Research Council (2013), instructional laboratory activities help students to

(1) enhance mastery of subject matter,
(2) develop scientific reasoning,
(3) understand the complexity and ambiguity of empirical work,
(4) develop practical skills,
(5) understand the scientific process,
(6) stimulate an interest in science, and
(7) foster teamwork.

The pandemic posed challenges to this core hands-on nature and cooperative form of laboratory work.

During the pandemic, universities, among all educational establishments, were led to the physical closure of buildings and suspension of face-to-face interactions sustaining the continuity of the learning process in a distance learning mode. As Mehrotra et al. (2001) noted, all interactions through distance learning

> "can now be synchronous (occurring simultaneously) or asynchronous (occurring at different times), with the latter providing additional flexibility in students' and instructors' schedules […] Web-based courses could be taken anywhere an Internet connection existed and any time of the day or night" (p. 3).

A survey of in-service teachers' opinions of the challenges when implementing a distance learning for science, outlined "less hands-on, inquiry, and exploration and investigation" (88%), "less student collaboration and discourse" (76%), "issues students face using technology" (59%), "low student participation, motivation, and engagement in science online" (55%), and "lack of science materials and supplies for students" (55%) (Macias et al., 2022b). In a companion brief based on the same data (Macias et al., 2022a), it was reported that a small group of teachers cited that capitalizing on flexible schedules, using familiar low-cost materials for the investigations and encouraging student ownership of the new learning environment as the reasons behind increased engagement and learning during distance learning.

It has been well established for decades that grouping students to work for a common goal is more effective for learning than competitive or individualistic methods (Johnson & Johnson, 1985; Okebukola, 1985; Watson et al., 1991), that students develop a better attitude towards their co-learners and improve their self-esteem (Slavin, 1996). Students' attention, effort and learning are enhanced by performing experiments and participating in argumentation (Crouch & Geller, 2023), but whether distanced versions of them are (dis)advantageous for students to enhance their self-efficacy apart from the conceptual learning outcomes that they provide, remains understudied. This specific laboratory course about thermal concepts was considered suitable for this investigation as it is entirely based on engagement with activities using inexpensive and everyday materials (i.e., can be duplicated by students) and is designed for group homework.

LITERATURE REVIEW

Traditional and Non-Traditional Laboratory Work

Remote data acquisition apps, virtual simulations, and other kinds of computer-based processes have all differentiated the methods and practices of what have traditionally been considered as "hands-on" learning procedures (see Picciano et al., 2021; Siemens et al., 2015). Ma and Nickerson (2006) have described virtual labs as simulated laboratories on computers and remote labs like the real ones but using an equipment geographically detached compared to the physical investigation process of the traditional ones. The remote and virtual laboratories have been examined in prior research compared to what is considered traditional but without reaching a premise as to their effectiveness since some researchers considered them as barriers (Dewhurst et al., 2000; DiBiase, 2000) and others as useful addition (Finn et al., 2002; Raineri, 2001; Striegel, 2001).

Videos of demonstrations are equally appreciated and understood, while in some cases, there are indications of a more significant impact on their understanding (Kestin et al., 2020). A gratifying remark is that physical or virtual experimentation may be more appropriate depending on the concept under study (Chini et al., 2012), e.g., the virtual ones for abstract concepts (Zacharia & Olympiou, 2011) and the physical ones in cases, where tactile sensation plays a crucial role in students' comprehension (Zacharia et al., 2008). The blended approach (integration of face-to-face and online instruction) has been reported as an improved alternative benefiting the affordances of the two modes of experimentation and is considered better than each method alone (Means et al., 2009).

Regardless of the effectiveness of learning, students tend to view social interaction as a positive aspect of physics laboratory work (Roychoudhury & Roth, 1996). Hands-on experiences together with collaborative group work strengthen students' interest and attitudes (Dohn et al., 2009; Holmes & Lewandowski, 2020), and this, in turn, enhances learning (Laukenmann et al., 2003; Owen, 2008; Palmer, 2009). Working together allows the negotiation of students' understandings towards a consensus via discursive practices (Roth & Roychoudhury, 1994). However, this kind of collaborative engagement may do not necessarily have to occur in the same physical space. For example, a recent review (Brinson, 2015) suggested that student learning outcome achievement is equal or higher in virtual/remote laboratories versus traditional ones across all learning outcome categories: knowledge and understanding, inquiry skills, practical skills, perception, analytical skills, and social and scientific communication. Although student-student and student-instructor interactions frequently diminish in non-traditional laboratories (Cooper & Ferreira, 2009), interventions may be needed to achieve the same positive outcomes by supporting autonomy and providing educational feedback (Wang & Hazari, 2018).

Self-Efficacy Beliefs

Grounded in social cognitive theory, Bandura defined self-efficacy beliefs as "people's judgments of their capabilities to organize and execute courses of action required to attain designated types of performances" (Bandura, 1986, p. 391). "Cognitive content mastery (successes in understanding science content), cognitive pedagogical mastery (successes in understanding how to teach science) and simulated modelling (in which teaching is role played) are all sources of self-efficacy" (Palmer, 2006b, p. 340). Thus, self-efficacy beliefs among teachers involve both their belief in personal teaching abilities and outcome expectancies for students (Ramey-Gassert et al., 1996). Mintzes et al. (2013) highlighted that level of content knowledge and years of science teaching experience correlate with high levels of self-efficacy and concluded that "these findings suggest that the highest levels of self-efficacy are found in those who have a strong science background …" (p. 1203). Moreover, the number of minutes per week that science is taught (Desouza et al., 2004), the number of science courses students enroll in (at the high school and undergraduate level; Mintzes et al., 2013) and teaching science methodology courses (Cantrell et al., 2003; Palmer, 2001, 2006a) can significantly increase teachers' personal self-efficacy and outcome expectancies. Other studies support that prior science course experience and content knowledge have little impact on the belief systems of future teachers of science (Mashnad, 2008; Tosun, 2000). Contradictories are also found as to gender differences since Azar (2010) revealed no significant gender differences between professional teachers and pre-service teachers' personal self-efficacy beliefs and outcome expectations in teaching science, while previous work (Bleicher, 2004) reported higher personal science teaching self-efficacy among males than females.

The literature further adds psychological and motivational variables to the discussion: The positive interdependence between interest and self-efficacy has been well documented (Bong et al., 2015) indicating a reciprocal relationship (Hidi & Ainley, 2008; Uzuntiryaki, 2008). Students' engagement in science activities triggers personal interest, increasing their self-efficacy. In addition, student interest strengthens once competence and efficacy develop (Uzuntiryaki, 2008). Motivational factors are particularly important in understanding participation in distanced learning situations. Students with low levels of self-efficacy tend to lurk or not participate in online discussions (Amichai-Hamburger et al., 2016; Kuo et al., 2014) and those who do not feel comfortable with the technology (Chen et al., 2010). While students' learning outcomes in distanced laboratories have been examined (Brinson, 2015; Merchant et al., 2014), studies on students' interactions are lacking (Wei et al., 2019) and since those affect their overall interest and sense of engagement, understanding how students' level of self-efficacy change when academic interactions occur virtually is critical.

The Present Study

This study's double purpose was to assess the learning outcomes of a distanced laboratory course regarding thermal concepts and to investigate whether students' distanced participation differentiated their self-efficacy toward science teaching. The study's research questions were formulated as such

1. Does participation in a distanced laboratory course lead students to better understand thermal concepts?
2. Does distance learning enhanced future primary teachers' level of self-efficacy towards science teaching?

METHODOLOGY

Sample

A convenience sample was selected and included 63 undergraduate students enrolled in a department of primary education during their 3rd year of study. Students in the first two years of study had attended a compulsory course on the basic concepts of physics (mechanics, thermodynamics). Some had completed an elective course named "physics in everyday life", and an elective laboratory course.

Instruments

The instruments used for this study were the physics teaching efficacy belief instrument (PTEBI-B) (Stylos et al., 2021) and thermal concept evaluation (TCE) (Stylos et al., 2022; Yeo & Zadnik, 2001). Based on Bandura's two-component model, PTEBI-B is composed of two subscales:

(a) personal physics teaching efficacy beliefs (PPTEB) and

(b) physics teaching outcome expectations (PTOE). It is a modified version of the science teaching efficacy belief instrument (STEBI-B) (Bleicher, 2004; Enochs & Riggs, 1990) that was validated in Greek (Stylos et al., 2021).

It consists of 23 items scored on a 5-point Likert scale ranging from strongly disagree (=1) to strongly agree (=5). TCE test, developed and implemented by Yeo and Zadnik (2001), was also validated in Greek by Stylos et al. (2022) and consisted of 26 multiple-choice questions that measure students' misconceptions of thermal concepts.

Procedure

The courses took place at the laboratory for education and teaching of physics. The units and the expected learning outcomes of each course are presented in **Table 1**. The experiments were performed with everyday materials like recyclables (tin cans & plastic containers) sourced from the house with very few exceptions e.g., thermometers and light bulbs. Students attended the online courses with their desktop or laptop computers, and mobile devices (tablets & smartphones) through a meeting platform. In the initial stage, the educators elicited students' prior knowledge to inform teaching and learning. During the meeting sessions, educators carried out the planned experiments, which were redefined (re-execution, differentiation of materials or quantities, addition of extra features, etc.) because of the students' questions or comments. At the same time, the students recorded measurements in order to generate explanations, compare ideas, and relate evidence to explanations. Additionally, students had to validate their conclusions to different situations to understand the concept better. Pedagogical approaches as alternative conceptions targeting and real-world relevance were used to improve students' understanding and self-efficacy beliefs. In the last minutes of each meeting, students reviewed and reflected on their learning. For each course, homework was assigned to students' groups, including performing the demonstrated experiments with the corresponding observations and conclusions.

Statistical Data Analysis

To address the study's proposed goals the data were analyzed in the following steps: Firstly, data from the 26-item questionnaire were examined for item discrimination index e.g., D-values 20 and over (Chu et al., 2012). The pre-and post-tests to measure whether the expected changes took place in the participants in the laboratory courses were calculated using a nonparametric test (Wilcoxon signed-rank test) as the data deviated significantly from the normal range. In all analyses, total performance was used. The total performance of TCE test was estimated as the sum of the correct and wrong responses of the remaining items (correct responses were scored as one and incorrect as zero). The performances of the two PTEBI-B subscales were estimated as the sum of their responses recoding the negative items. All statistical analyses were performed with IBM SPSS v.28 statistical software.

Table 1. Units & expected learning outcomes

Course	Units	Expected learning outcomes: Students should …
Course 1	**Thermometer (types of thermometers & estimation-measurement)**	• find out experimentally that the estimation of temperature by our senses is not objective. • describe the construction, operation, and usefulness of mercury and alcohol thermometers. • measure the temperature of various bodies with the alcohol thermometer. • determine experimentally the melting point of ice and the boiling point of water. • describe how Celsius worked to determine his scale. • calibrate a calibration thermometer. • become familiar with the units of measurement of temperature.
Course 2	**Temperature-heat**	• distinguish the physical quantity "heat" from the physical quantity "temperature." • find out experimentally that when a body absorbs heat, its temperature increases. • recognize that heat is energy that is transferred between two bodies due to a difference in temperature. • establish experimentally that heat flows spontaneously from bodies with a higher temperature to bodies with a lower temperature. • determine experimentally how thermal equilibrium is achieved
Course 3	**Thermal expansion-contraction**	• relate the change in length or volume of a body to the change in its temperature. • establish experimentally that solids, liquids, and gases expand when heated. • establish experimentally that solids, liquids, and gases contract when cooled. • describe everyday applications of thermal expansion and contraction. • use the microcosm model to describe the thermal expansion and contraction of bodies.
Course 4	**Change of phase:** Evaporation & condensation	• describe examples from everyday life where changes in the state of matter are observed. • relate changes in the state of matter to a change in the way molecules move rather than in their composition. • interpret phenomena using the microcosm model. • establish experimentally that ice melts at a given temperature. • establish experimentally that the temperature remains constant as long as the ice melts. • define melting as the change of state from a solid to a liquid. • establish experimentally that in order for a body to change from a solid to a liquid, it must absorb energy. • establish experimentally that water solidifies at a given temperature. • establish experimentally that the temperature remains constant as long as water solidifies. • define coagulation as the change of state from liquid to solid. • establish experimentally that the freezing temperature of a body is equal to its melting temperature. • define evaporation as the change of state from liquid to gas when it occurs from the free surface of the liquid. • establish that during evaporation the liquid absorbs energy. • define condensation or liquefaction as the change of state from a gas to a liquid. • find that during liquefaction the gas gives up energy. • define boiling as the change of state from liquid to gas when it occurs throughout the liquid. • establish experimentally that the boiling temperature of the water is specific. • establish experimentally that the temperature remains constant for the duration of the boiling of water. • distinguish between the phenomenon of evaporation and the phenomenon of boiling.
Course 5	Boiling, melting, & freezing	• define boiling as the change of state from liquid to gas when it occurs throughout the liquid • establish experimentally that the boiling temperature of the water is specific • establish experimentally that the temperature remains constant for the duration of the boiling of water • distinguish between the phenomenon of ev - find out experimentally that ice melts at a certain temperature • establish experimentally that the temperature remains constant as long as the ice melts • define melting as the change of state from a solid to a liquid • establish experimentally that in order for a body to change from a solid to a liquid, it must absorb energy • establish experimentally that water solidifies at a given temperature • establish experimentally that the temperature remains constant as long as water solidifies • define coagulation as the change of state from liquid to solid. • establish experimentally that the freezing temperature of a body is equal to its melting temperature operation and the phenomenon of boiling.
Course 6	**Heat transfer:** Conduction & insulators	• determine experimentally the transmission of heat by conduction in a solid body. • establish experimentally that heat is transmitted from the hottest to the coolest part of the object. • distinguish between different materials as good or bad conductors of heat. • identify applications of good and bad conductors of heat in everyday life. • interpret heat transfer by conduction using the microcosm model.
	Convection & radiation	• determine experimentally the heat transfer by currents in liquids and gases. • observe that heat transfer by currents moves matter, as opposed to conduction heat transfer. • distinguish between heat transfer by currents and heat transfer by conduction. • identify applications of current heat transfer in everyday life. • interpret the microcosm model of heat transfer by currents.
	Radiation	• determine experimentally the propagation of heat by radiation. • recognize that radiative heat propagation is also possible in a vacuum. • explain why radiative heat transfer the only way in which energy is can flow from the Sun to the Earth. • establish experimentally that material bodies absorb and emit heat. • establish experimentally that dark-colored bodies absorb heat more than light-colored bodies. • identify applications of radiant heat propagation in everyday life. • to interpret radiative heat propagation using the microcosm model.

Table 2. Descriptive statistics of pre- & post-test performance of TCE

	n	Mean performance (%)	Standard deviation
Pre-test	63	37.07	19.49
Post-test	63	57.20	17.90

Table 3. Comparison between students' pre- & post-test performance of TCE

	n	Mean rank	z	p-value
Pre-test	63	16.72	-3.208	0.001
Post-test	63	25.36		

Table 4. Descriptive statistics of pre- & post-test scores of PTEBI-B dimensions

PTEBI-B	Test	n	Mean performance (%)	Standard deviation (%)
PPTEB	Pre-test	63	48.29	6.06
	Post-test	63	60.84	6.03
PTOE	Pre-test	63	39.09	3.73
	Post-test	63	39.20	3.52

Table 5. Comparison between students' pre- & post-test scores of PTEBI-B dimensions

PTEBI-B	Test	n	Mean rank	z	p-value
PPTEB	Pre-test	63	13.50	-3.756	.001
	Post-test	63	25.95		
PTOE	Pre-test	63	17.10	-.142	.887
	Post-test	63	20.25		

RESULTS

Students' Performance in the Thermal Concept Evaluation Test

TCE items that did not meet the minimum discrimination value were: 1, 4, 6, 8, 11, 12, 17, 25, and 26. The mean discrimination value for the rest 17 items was 0.46. In order to examine the reliability of the test, the items were coded as binary items (wrong-correct) and the Kuder-Richardson's coefficient was used (KR20). KR20 coefficient for the test was 0.63 and is considered reasonable (Glen, 2020). **Table 2** and **Table 3** present the pre- and post-test's mean performance and pairwise comparisons, respectively. Wilcoxon signed-ranks test indicated that post-test performance was significantly higher than pre-test performance (z= -3.208 & p=0.001).

Students' Performance in the Physics Teaching Efficacy Belief Instrument–B Dimensions

Table 4 and **Table 5** present the mean performance of the two PTEBI-B dimensions of the pre- and post-test and their pairwise comparisons, respectively. Wilcoxon signed-ranks test indicated that post-test score of PPSTE dimension was significantly higher than pre-test score (z=-3.208 & p=0.001).

DISCUSSION

We must acknowledge that the forced distanced mode brought by the pandemic cannot be equated to a designed-from-scratch effort of e-learning. Both students and teachers were initially unprepared thus the course was formatted as an imitation of the normal: The students, through appropriate questions, ascertained the conclusions of an experiment carried out by the hands of the instructors as a demonstration, and then they were forming new related experiments at home. The main aim of the experiments was to develop group discussion as an attempt to involve the students actively; thus as Dallimore et al. (2008) argue, this helps students practice the transformation of ideas into words by developing, organizing, supporting, and presenting arguments.

When discussing about learning-oriented laboratory work, cooperation is a key point since in general, collaborative teams tend to produce more gains compared to individuals working alone (Wuchty et al., 2007), but also it constitutes a main challenge for distanced learning approaches. The only way to reverse this difficulty was by assigning group homework to design, carry out, and present their experiments. Students in online learning tend to lurk more because it is not as easy to be called by the instructors directly when they seem disoriented (Dallimore et al., 2006). The teaching staff tried to motivate students to participate by answering questions and putting forward ideas for on-the-spot progression of activities, engaging them to their own learning, thus trying to improve their performance and satisfaction (Bonwell & Eisen, 1991).

The specific online course concerning thermal concepts based on demonstrations of physics experiments generated significant statistical differences in students' understanding. Based on the literature, the results may have been more optimistic if the course had been set up in a guided-inquiry form. This is because the experimentation mode yields better results on learning outcomes and attitudes toward physics compared to verification-type activity (Saputra et al., 2020).

Appropriate instructional approaches involving students' engagement in firsthand experiences and not just passively observing (Christonasis & Kotsis, 2022), evidence collection, and multiple representations all help students to construct scientific understanding (Adadan & Yavuzkaya, 2018; Stevens et al., 2010).

Indisputably the approaches of alternative conceptions targeting and real-world relevance, which relate to established efficacy sources (mastery experiences, verbal persuasion, emotional arousal, & cognitive content mastery), may have contributed to the increase of post PPTE's levels (Deehan et al., 2017). Similar to other studies Their teaching outcome expectations remained unchanged (Deehan, 2017). Innovative practices as in-subject practical experience, inquiry learning and curriculum development covary positively with growth on the personal physics teaching efficacy scale (Bautista, 2011; Deehan, 2017). Increasing teachers' confidence should be a pillar of teachers training programs given that pre-service teachers have a phobic attitude towards science teaching (Saputra et al., 2020), possible progression of a poor interest during all levels of the education system (Owen et al., 2008).

CONCLUSIONS

This study investigated the impact of a distanced intervention on students' understanding of thermal concepts and self-efficacy beliefs based on live interactive demonstrations of experiments. The results showed that the post-test performance was not as adequate as we would assume, despite being statistically significant. This recognition raises concerns about the effectiveness of the specific type of distanced approach, raising interest of a future comparison to an identical, in terms of content and procedure, face-to-face intervention.

The fact that a sense of self-efficacy was positively affected by the intervention supports the thesis that any form of experimentation results in improved attitude and that is why in addition to the acquisition of theoretical knowledge, a strong link with practical teaching experience is essential during teacher training.

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