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Research Article

Impact of inquiry-based laboratory activities on understanding heat concepts and self-efficacy in pre-service teachers

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This study investigates the influence of inquiry-based laboratory activities on the understanding of heat concepts and the self-efficacy beliefs of pre-service primary teachers. Recognizing that both scientific literacy and teaching efficacy are critical for effective science education, this research aims to determine how inquiry-based laboratory tasks can enhance these attributes. The study involved 39 pre-service teachers participating in a sequence of eight three-hour courses. Assessments of conceptual understanding and self-efficacy beliefs were conducted before and after the intervention. The results indicate significant improvements in both areas, suggesting that hands-on, inquiry-based learning can effectively enhance scientific understanding and teaching confidence. These findings underscore the importance of integrating such methodologies into programs for teacher education to prepare future educators for fostering scientific literacy in their students.

Keywords: Heat concepts; Inquiry; Self-efficacy

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1. Introduction

Physics, as a subject, requires strong analytical abilities in both students and educators. It differs from other fundamental sciences as requires students to spend more time to grasp a scientific subject fully (Hasanah, 2021). To achieve the objective of a scientifically literate society, it should be taken into consideration how to adequately train pre-service teachers to teach science (Walag et al., 2022).

A scientifically literate person understands scientific laws, physical phenomena, and objects (Dragoş & Mih, 2015; Tsoumanis et al., 2023). Also, it is regarded as an indicator of a country's science education quality (Rubini et al., 2016). Related research concurs that teacher with low scientific literacy, including pre-service and in-service, cannot be anticipated to raise and create scientifically literate learners (Flores, 2019).

Scientific literacy and science teaching efficacy influence how science teachers teach (Walag et al., 2022). The association of self-efficacy [SE] and scientific literacy resulted in a significant correlation. This is consistent with Riyadi et al.'s (2018) research, which found a positive, strong, and important relationship between SE and scientific literacy. This study finds that there is a

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positive and substantial connection between prospective physics instructors' personal efficacy and scientific literacy competence (Latifah et al., 2019).

In this context, the present study aims to explore the impact of laboratory-based exploratory activities on both the comprehension of heat-related concepts and phenomena and the SE beliefs of preservice primary teachers. By addressing these dual aspects, the research seeks to determine whether such hands-on, inquiry-driven methods can enhance scientific understanding and boost the confidence of preservice teachers in their teaching abilities. The study is designed to measure the changes in students' conceptual grasp and SE both prior to and following the intervention, thus providing insights into the effectiveness of integrating inquiry-based learning strategies in teacher education programs.

2. Purpose of Research-Research Questions

The purpose of the present study is to examine the effect of laboratory exploratory activities on the understanding of concepts and phenomena of heat as well as on the self-efficacy beliefs of future teachers. The research questions of the study were:

RQ 1) How do laboratory-research activities affect the understanding of heat concepts and phenomena from students?

RQ 2) How do laboratory-research activities affect self-efficacy beliefs of future teachers?

RQ 3) Are there statistical differences in the conceptual understanding of students in the concepts and phenomena of heat before and after the teaching interventions?

RQ 4) Are there statistical differences in students' self-efficacy beliefs before and after the teaching interventions?

3. Literature Review

3.1. Increasing Self-Efficacy through Inquiry

Previous research has found that many pre-service and in-service educators lack confidence in their abilities to teach science and assist students to learn (Cakiroglu et al., 2012; Demirel & Caymaz, 2015). Therefore, divisions of primary education should place a greater focus by promoting new methods so that SE be included in teacher education institutes (Demirel & Caymaz, 2015). Preliminary findings, in-class physics instruction still does not effectively help students in increasing their SE and scientific literacy. The cause is related to the commonly used methods of lecture and discussion. One approach to overcoming this issue is to use an inquiry-based learning strategy (Latifah et al., 2021).

According to Kandil and Işıksal Bostan (2018), the inquiry-based learning model increases students' self-efficacy since they are encouraged to work on a topic, inquire, observe, make assumptions, acquire data, and present their conclusions by relating their prior knowledge. Experiments during learning serve to gain information by inviting students to search, try, and achieve their concepts in groups. In conclusion, the general outcomes of the SE and scientific literacy taught through the inquiry-based learning model are greater than the mean results of the traditional methodology.

3.2. Self-Efficacy Beliefs

Aside from scientific literacy, more emphasis lately has been placed on the affective aspects that determine learning outcomes. As a result, the aspect known as self-efficacy needs to be examined, to overcome these challenges. SE is a self-evaluation of one's ability to organize and execute the steps required to accomplish specific results (Latifah et al., 2021).

More specifically self-efficacy can be defined as “the teacher's belief that can affect how effectively students learn, even those who may be difficult or unmotivated' (Guskey & Passaro, 1994). Bandura suggested two dimensions of SE:

- personal efficacy as «the beliefs in abilities someone has to achieve a goal»

- the expected outcome as «a person's estimate that a given behavior will lead to certain results» (Menon, 2018).

Before planning appropriate activities to strengthen teachers' beliefs towards the effectiveness during teacher training programs, it should be established whether their SE levels are high or low (Aydin & Boz, 2010). In addition, it should be noted that in order to improve self-efficacy beliefs once they are established a lot of effort is required (Bandura, 1997). Studies have shown that teacher SE is associated with the effort and persistence in dealing with teaching challenges, their adaptability to new teaching methods and strategies to address students' problems (Mojavezi, & Tamiz, 2012).

Efficacy beliefs determine whether teachers will try to deal with a difficult situation and how much time they will spend on it (Bandura, 2006). Alternatively, our ability to forecast people's motivations and decisions is guided by their self-efficacy beliefs. Since college students will eventually become teachers themselves, it is essential to ascertain their levels of SE in the classroom (Aydin & Boz, 2010).

Many researchers have conducted studies in order to measure SE. A literature review suggests that teacher's SE can be done based on students' performance (Azar, 2010). Several studies have been done to determine how teachers' self-efficacy beliefs affect children's performance and achievements at school (Muijs & Rejnolds, 2001; Tournaki & Podell, 2005). The correlation between teachers' SE and students' performance has been analyzed in many studies where it can be concluded that teacher SE positively affects student attitudes (Tschannen-Moran & Hoy, 2001).

Many studies (Mulholland & Wallace, 2001; Velthuis et al., 2015.) have shown changes and development in the beliefs of teachers' effectiveness through certain training courses, such as practical courses. Narayan and Lamp (2010) concentrated on investigating factors that influence SE of teachers in physics tuition, the participants reported improvement in their self-efficacy beliefs through engaging research-based activities. A second aspect that has been associated with higher levels of SE is pedagogical understanding of science. For instance, Appleton (1995) discovered that using constructivist teaching strategies in a scientific course helped students' to be confident in their competence to teach the subject (Palmer, 2006).

In other words, the most effective method το enhance educators' science teaching SE is a balance between courses using scientific methods and courses with scientific content. The lessons that utilize scientific methods aim to guide pre-service teachers' skills for teaching science, such teaching strategies and classroom management techniques, while science courses content aims to guide them about science itself (Azar, 2010). However, simply increasing science content may have slight impact on teachers' self-efficacy beliefs (Schoon & Boone, 1998). One reason is that having alternative understandings of various scientific concepts interferes with learning (Nussbaum & Novick, 1982).

SE does not depend on age or the type of school they graduated from, however teachers who consider themselves more competent also have high levels of self-efficacy (Palmer, 2006). Also, it was found that one of the factors affecting self-efficacy beliefs are constraints from students, parents (Azar, 2010). Although, efficacy beliefs do not seem to depend on gender, some studies suggest that female students tend to have a stronger sense of efficacy (Evans & Tribble, 1986), however others find an opposite effect or no difference (Cantrell et al., 2003; Mulholland et al., 2004). This was justified because the profession of teacher is chosen more by women (Gencer & Cakiroglu, 2007).

3.3. Self-Efficacy Instruments

Various tools appear in the literature that quantify SE depending on the scientific field as well as the educational level of the trainees. For example, the Current Statistics Self Efficacy [CSSE] measures self-efficacy beliefs in college students' of statistics departments (Finney & Schraw, 2003) and Self-Efficacy in Technology and Science [SETS] in secondary school students (Hu et al., 2022). Apart from STEBI, another tool is Self-Efficacy Beliefs of Prospective Elementary Teachers about

Equitable Science Teaching and Learning [SEBEST] (Cone, 2009). SEBEST is a modification of [STEBI-B] which was developed by Ritter et al. (2001). It comprises of 34 items and measures the self-efficacy beliefs of potential Science teachers for diverse students. Ritter et al. (2001) define diverse students as those groups which are underrepresented in science-related fields (e.g., racial/ethnic minorities and women) and people from low socioeconomic background.

Riggs and Enochs (1990) firstly created their instrument [STEBI] to specifically measure elementary school teachers' SE. Then, they adapted the original into two instruments, the STEBI-A (Inservice Teachers' Science Teaching Efficacy Beliefs) designed to measure the effectiveness in science teaching of active primary school teachers while the STEBI-B was intended for measuring the effectiveness in science teaching of potential primary school teachers (Deehan et al., 2017). STEBI-B removed two of the original questions from STEBI-A, modified the verb tenses to correspond with future orientation and retained the naming of the two subscales (Bleicher, 2004). The STEBI instruments consist of questions divided into two subscales, self-efficacy beliefs and outcome expectations (Andersen, 2004).

The Personal Science Teaching Efficacy Belief [PSTE] and Science Teaching Outcome Expectancy [STOE] are the subscales of the STEBI-B which is a five-point Likert-type instrument that ranges from 1 "strongly disagree" to 5 "strongly agree". The PSTE consists of 13 questions on the other hand, STOE consists of 10. A high score on the PSTE indicates high self-efficacy in science teaching, high score on STOE implies high outcome expectation for science teaching. For example, "If students do not perform well on science, it is probably due to inadequate teaching of science", "The performance of students in science courses is teacher's responsibility " are some sentences from the STOE subscale while "I know the necessary strategy for teaching science" and "I understand science concepts decently to be effective in teaching science" some for the PSTE subscale (Aydin & Boz, 2010). In literature STEBI-B appears to have some inconsistency between the PSTE and STOE subscales. More specifically, the PSTE subscale resulted in higher mean score and rate improvement compared to STOE subscale (Deehan, 2017). The STOE subscale is influenced by factors such as personal scientific experiences. Furthermore, outcome expectations have been shown to be associated with SE (Deehan et al., 2017). Since SE is an internal belief, it can only be measured by asking the participants to evaluate themselves (Gray, 2017).

3.4. Students' Alternative Conceptions

According to constructivist theory, students in science courses have pre-existing ideas that have been created from daily experiences or through previous teaching (Vosniadou, 2013). Thermodynamics, mechanics, and electricity involve phenomena that are common in everyday experience but not clearly understood (Georgiou & Sharma, 2012). Studies indicate that understanding scientific concepts is challenging because misconceptions tend to persist (Stylos & Kotsis, 2023).

The ideas surrounding heat and temperature, thermal balance, thermal conductivity, and transitions between states of matter (evaporation, boiling, freezing) present numerous alternative concepts for students (Stylos & Kotsis, 2023). Previous research has shown the gap between students' and teachers' conceptual beliefs about heat can be attributed as the main barrier to understanding this concept (Deehan et al., 2017). Studies have related these alternative perceptions of students to the daily use of the concepts of "hot" and "cold" (Wiser & Amin, 2001), the unclear definitions in textbooks, the improper application of terms like "heat" and "temperature" in everyday speech and the ineffective teaching methods (Gray, 2017).

Regarding students' conceptions of heat, there are two common alternatives ideas on heat among students. First, heat is often perceived as an inherent quality of a matter (Stylos et. al, 2021). For example, the heat is an inherent characteristic of wood and cold is a characteristic of ice. Comprehension of thermal transfer is often lacking clarity in students with this framework (Azar, 2010). Secondly, students tend to view heat as a substance, similar to the release of air from a source (Chiou & Anderson, 2010; Georgiou & Sharma, 2012). In this context, heat and temperature are difficult to distinguish and temperature is referred to as a measure of the heat of an object (Stylos et al., 2021).

According to students' beliefs, temperature indicates the quantity of heat present within a substance (Kesidou & Duit, 1993). In addition, some of them still interpret temperature as the sensation of hot or cold (Stylos & Kotsis, 2023). They also have the tendency to sum the different degrees of two distinct water samples when combined (Paik et al., 2007). Because of the confusion between the concepts of heat and temperature, learners commonly held the belief that temperature was transferred from a warm item to a cold one (Georgiou & Sharma, 2012). In other studies, learners perceived that a metal spoon and a wooden spoon had different temperatures even when immersed together in the same glass of water, at the same time, for some period (Chiou & Anderson, 2010; Chu et al., 2012).

About thermal conductivity, students believe that certain objects, like rug or wood, retain heat better than metal or glass, as metal objects often feel colder (Georgiou & Sharma, 2012). Students also believe that certain items, such as quilts and clothing, keep us warm by producing heat (Chu et al., 2012). Likewise, glass or aluminum are effective at keeping drinks cold, as they are cold materials and maintain lower temperatures (Stylos et al., 2023).

A common students' misinterpretation about phase changes is that adding heat to a system invariably results in an increase in temperature, which indicates no understanding the preservation of a constant temperature throughout the process of change (Kotsis et al., 2023). Similarly, in another study it has been found that students assume that the temperatures of boiling water and its steam are higher than 100°C (Adadan & Yavuzkaya, 2018).

3.5. Inquiry-Based Teaching

Inquiry-based teaching is a process which invites students to respond to research questions through their own data analysis. By the above definition of inquiry, it is concluded that (Grandy & Duschl, 2007): questions do not come exclusively from the students, this happens only in the open. It is not necessary for the data to be collected by the students themselves. What is important is that students answer the research question through their own analysis of the data. Activities that include internships e.g. measurements with scientific instruments, etc. are part of the investigation but does not constitute an investigation itself (Manoli et al., 2015). The four levels of inquiry and teachers' amount of intervention are demonstrated (see Table 1).

Table 1
Characteristics of each level of inquiry (adapted from Buck et al., 2008)

Characteristic	*Level 1: Confirmation*	*Level 2 : Structured inquiry*	*Level 3: Guided inquiry*	*Level 4: Open inquiry*
Problem/Question	Provided	Provided	Provided	Provided
Theory/Background	Provided	Provided	Provided	Provided
Procedures/Design	Provided	Provided	Provided	Not provided
Results analysis	Provided	Provided	Not provided	Not provided
Results communication	Provided	Not provided	Not provided	Not provided
Conclusions	Provided	Not provided	Not provided	Not provided

4. Method

4.1. Research Design

The current study is based on a quantitative research method and a quasi-experimental pre-post design. This design tries to assess the impact of an intervention (inquiry-based laboratory activities) on two key variables: conceptual understanding of heat concepts and self-efficacy beliefs in teaching science. It uses statistical methods such as paired sample t-tests to compare pre- and post-test scores (Estrada et al., 2020) and descriptive statistics (means and standard deviations) to summarize the overall changes. Given that the study measured two variables the analysis focused on comparing participants' scores before and after the intervention to determine if the inquiry-based laboratory activities had a significant impact.

4.2. Participants

The research was conducted during the spring semester of the 2022-2023 academic year. 39 third-year students of the Department of Education of Primary Education of the University of Ioannina who participated in the course "Laboratory Approach to Physics Concepts". The teaching intervention, which consisted of eight three-hour courses, was the guided and confirmatory inquiry. A closed-ended questionnaire was distributed before and after the intervention. The time required to complete the questionnaire was 40 minutes.

4.3. Research Instruments

The research tool consists of three parts. The first part measures SE of the students regarding the teaching of Physics. The Physics Teaching Efficacy Belief Instrument (PTEBI-B) was selected (Stylos et al., 2022) which is a modified version of the STEBI-B of Enochs and Riggs (1990). The specific questionnaire consists of 23 sentences on a five-point Likert scale, with the following possible answers: 1= "strongly disagree", 2= "disagree", 3= "neutral - unsure", 4= "agree", 5= "disagree" very". In this version, the term science has been replaced by "physics". The PTEBI - B consists of two subscales consistent with Bandura's theory. The PPTE (Personal Physics Teaching Efficacy) subscale relates to self-efficacy in teaching Physics and includes the following 13 propositions: 2, 3, 5, 6, 8, 12, 17, 18, 19, 20, 21, 22 and 23 , while the PTOE (Science Teaching Outcome Expectancy) subscale concerns the expected learning outcomes from teaching the subject of Physics and includes the following 10 sentences: 1, 4, 7, 9, 10, 11, 13, 14, 15 and 16.

The second part of the questionnaire used to evaluate the extent to which the students had adopted scientifically sound concepts and is the Thermal Concept Evaluation [TCE] (see Appendix 1) created by Yeo and Zadnik (2001). The questionnaire addresses basic thermal concepts such as heat, temperature, thermal conductivity and phase changes. To the TCE questionnaire which includes 26 questions, another 4 questions created by the researchers were added (Stylos et al., 2021). Which were based on daily thermal phenomena that the students have experienced both in past and in their everyday life. Each question was created so that its answers contained one or more misconceptions. Many researchers have employed the questionnaire in different levels of education (Adadan & Yavuzkaya, 2018; Chu et al., 2012; Stylos et.al, 2021).

4.4. Teaching Intervention

4.4.1. Course 1 (Thermometer, types of thermometers, estimation-measurement)

During the first course students found out experimentally that the estimation of temperature by our senses is not objective (Figure 1), were able to describe the construction, operation, and usefulness of mercury and alcohol thermometers. Also, they measured the temperature of various

Figure 1

Estimating the temperatures by sense

bodies with an infrared thermometer (Figure 2) and determine experimentally the melting point of ice and the boiling point of water. Lastly, they calibrated a calibration thermometer and became familiar with the units of measurement of temperature (Celsius, Fahrenheit, Kelvin).

Figure 2
Measuring the temperatures of three objects (cotton, wood, metal)

4.4.2. Course 2 (Temperature, heat)

In the second course students were able to distinguish the physical quantity "heat" from the physical quantity "temperature" and to find out experimentally that when a body absorbs heat, its temperature increases. In addition, the course guided students to recognize that heat is energy that is transferred between two bodies due to a difference in temperature and that heat flows spontaneously from bodies with a higher temperature to bodies with a lower temperature. Furthermore, how thermal equilibrium is achieved was also experimentally determined (Figure 3).

Figure 3
Experimental setup for the thermal equilibrium (Stylos & Kotsis, 2021a)

4.4.3. Course 3 (Thermal expansion, contraction)

This course led students to relate the change in length or volume of a body to the change in its temperature. Experimentally students found out that solids, liquids, and gases expand when heated and contract when cooled. Also, students after the course could use the microcosm model to explain the thermal expansion and contraction of bodies (see Figure 4 and Figure 5).

Figure 4
Testing thermal expansion of solids aluminum foil (Stylos & Kotsis, 2021a)

Figure 5
Testing thermal expansion of gases

4.4.4. Course 4 (Evaporation, condensation)

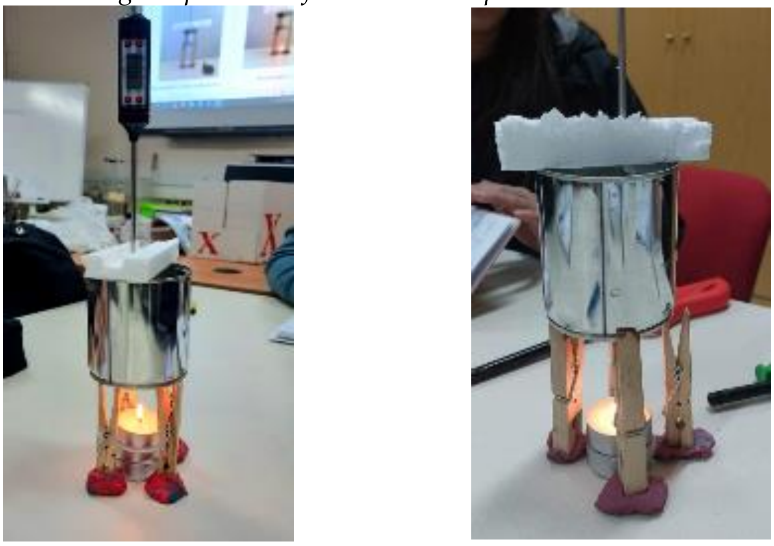
Students after the fourth course are expected to relate changes in the state of matter to a change in the way molecules move rather than in their composition. Also, they were able to define evaporation and condensation or liquefaction. This was succeeded by establishing experimentally that temperature remains constant as long as a body changes phase, a body to change from a solid to a liquid it must absorb energy, during evaporation the liquid absorbs energy and that during liquefaction the gas gives up energy (see Figure 6).

Figure 6
Investigating which factors affect evaporation

4.4.5. Course 5 (Boiling, melting, and freezing)

The fifth course helped students to define the procedures of boiling, melting and coagulation. Students experimentally found out that changes in phase of water occur at a certain temperature. Moreover, water in order to boil absorbs energy and during freezing gives up (see Figure 7).

Figure 7
Measuring temperature of water in each phase



4.4.6. Course 6 (Conduction, insulators)

Students during sixth tuition found out through experiments that heat is transmitted from the hottest to the coolest part of the object, which materials are good or bad conductors of heat, and they use in everyday life (see Figure 8). Furthermore, the transmission of heat by conduction in a solid body was experimentally examined (see Figure 9).

Figure 8
Experimenting heat transmission through conduction (Stylos & Kotsis, 2021b)

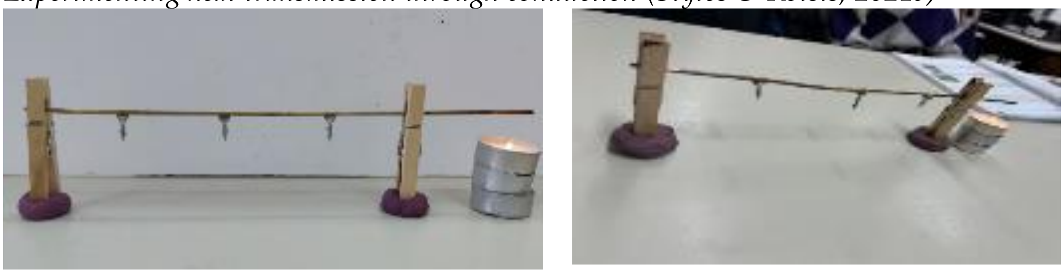


Figure 9
Examining which materials are good or bad conductors of heat

4.4.7. Course 7 (Convection)

In this course, it was determined experimentally that heat transfers by currents in liquids and gases by moving matter, as opposed to conduction heat transfer (see Figure 9). After these courses, students could distinguish heat transfer by currents and heat transfer by conduction and use the microcosm model to explain heat transfer by currents (see Figure 10).

Figure 9
Observing heat transfer by currents in liquids

Figure 10
Visualizing air currents of heated air

4.4.8. Course 8 (Radiation)

Students in the last tuition investigated experimentally the propagation of heat by radiation and that it differs from the other two ways because is also possible in vacuum. Moreover, by testing several material bodies students concluded that dark-colored bodies absorb heat more than light-colored and that all materials absorb and emit heat (see Figure 11).

Figure 11
Examining heat transfer through radiation and measuring the temperature of dark-colored and light-colored bodies

Figure 11 continued

4.5. Statistical Data Analysis

The TCE questionnaire responses were coded. The correct answers were recoded and received the value 1, while incorrect answers received the value 0 so that the scores achieved by the students before the intervention were calculated. Then the statistical significance of the 32 questions used in the first phase was examined in order to identify the questions that would be excluded. This process aims to improve the validity and reliability of the tool. According to the classical theory of question analysis (Allen & Yen, 2001). The questions used in a questionnaire are very important as they affect the overall score that one will succeed. The classical theory of question analysis is mainly expressed by two indexes: (a) the difficulty index and (b) the discrimination index. Based on the values of the above indicators for each question, the following questions were deemed inappropriate and removed: 8, 12, 17, 18, 21, 23, 25, 26 and 27.

The score achieved by each student in the self-efficacy questionnaire, both before and after the intervention, was calculated as follows: First the responses were coded on a five-point Likert scale as follows: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral - Uncertain, 4 = Agree, 5 = Strongly Agree. Then, the negatively worded questions (3, 6, 8, 10, 13, 17, 19, 20, 21 and 23) were recoded to positive, by reversing the answers (1=5, 2=4, 3=3, 4=2, 5=1). Then, the sums of the students' individual scores for the two subscales (PTOE and PPTE) of the PTEBI-B were calculated, both before (prePPTE and prePTOE) and after (postPPTE and postPTOE) the course. Finally, these scores were divided by the number of questions. To determine if there are any differences in scores before and after the intervention, the mean of the dependent variable, i.e. the score between initial (pre) and final (post) for both PTEBI B and TCE, was calculated. The non-parametric Wilcoxon Signed-rank test was also used to investigate whether there is a statistically significant difference. This specific test was used because our sample is small and does not follow the normal distribution. All statistical analyses were performed with IBM SPSS v.28 statistical software.

To assess the distribution of the collected data, statistical analyses tests were conducted as presented in Table 2. Skewness helps determine the symmetry of the data, as highly skewed distributions may violate the assumptions of parametric tests. Kurtosis measures the "tailedness" of the data, identifying whether the dataset has more extreme values than expected under a normal distribution. The Shapiro-Wilk test formally tests for normality, with p-values below 0.05 indicating significant deviations from a normal distribution (Razali & Wah, 2011).

The results in Table 2 provide insights into the distribution characteristics of each variable based on skewness, kurtosis, and the Shapiro-Wilk test. Skewness values of (PreTCE, PrePPTE, PrePTOE) are positive, indicating that these distributions are right-skewed and (PostTCE, PostPPTE, PostPTOE) are negative, indicating left-skewed distributions. Kurtosis values of (PreTCE, PrePPTE, PrePTOE) are positive, suggesting that these distributions have heavier tails and sharper peaks, meaning more extreme outliers are present compared to a normal distribution.

Table 2
The values of Skewness, Kurtosis and Shapiro-Wilk test.

Variable	*Skewness*	*Kurtosis*	*Shapiro-Wilk*
preTCE	1.836	3.147	0.020
postTCE	−1.654	−2.263	0.015
prePPTE	1.425	2.747	0.030
postPPTE	−1.214	−1.831	0.010
prePTOE	1.604	3.047	0.005
postPTOE	−1.514	−2.587	0.001

Post kurtosis values are negative, indicating that these distributions are flatter with lighter tails, meaning fewer extreme values than expected under a normal distribution. The p-values of all variables for the Shapiro-Wilk test are all below 0.05 which indicates that none of the variables follow a normal distribution.

5. Results

5.1. Findings from the Physics Teaching Efficacy Belief Instrument

The descriptive statistics for the pre- and post-test scores on two subscales of the PTEBI-B questionnaire are presented in Table 3. The Table 3 provides insights into the number of participants (N = 38), the minimum and maximum scores, the mean scores, and the standard deviations for each subscale before and after the intervention. These descriptive statistics help to summarize the data and offer a preliminary understanding of how the inquiry-based laboratory activities influenced the participants' teaching efficacy and outcome expectancy beliefs.

The Wilcoxon Signed-Rank Test was chosen as it is a non-parametric method suitable for analysing paired data that may not meet the assumptions of normality. The results are presented (see Table 4) with the Z-values and p-values, which indicate the direction and significance of the observed differences between pre- and post-test scores.

Table 3
Descriptive analysis of responses for the two subscales of the PTEBI-B questionnaire

Variable	*N*	*Min*	*Max*	*Mean*	*SD*
prePPTE	38	2.85	4.62	3.60	0.42
postPPTE	38	3.00	5.00	3.82	0.55
prePTOE	38	3.00	4.90	3.78	0.43
postPTOE	38	2.90	5.00	3.78	0.54

Table 4
Wilcoxon signed-rank test results for PTEBI- B questionnaire

Variable	*Z*	*p*
postPPTE-prePPTE	−2.727	.006
postPTOE-prePTOE	−0.162	.872

PPTE subscale: From the results of the Wilcoxon Signed-rank test it emerged that there were statistically significant differences as ($Z = -2.727$, $p < .05$) (see Table 4). Also, after the intervention, the mean score of the participants (M = 3.82) was greater than the corresponding mean before the intervention (M = 3.60) (see Table 3). Therefore, we conclude that the inquiry based intervention resulted in a statistically significant increase in PPTE subscale scores.

PTOE subscale: From the results of the Wilcoxon Signed-rank test it emerged that there were no statistically significant differences as ($Z = -0.162$, $p > .05$) (Table 4) regarding the PTOE subscale. In addition, after the teaching intervention, the average score of the participants was (M = 3.78) with almost no difference from its pre-intervention counterpart (M = 3.78) (see Table 3). We conclude that the intervention did not result in a statistically significant increase in PTOE subscale scores.

5.1. Findings from the Thermal Concept Evaluation Instrument

The Table 5 presents the descriptive statistics for the TCE questionnaire which includes the number of participants (*N* = 38), the minimum and maximum scores, the mean scores, and the standard deviations for both pre-test and post-test results.

The Table 6 shows the results of the Wilcoxon Signed-Rank Test conducted to assess the statistical significance of changes in participants' scores on the TCE questionnaire before and after the intervention. The test is used to determine whether the observed differences in paired scores (pre-test vs. post-test) are statistically significant.

Table 5
Descriptive analysis of responses for the TCE questionnaire

Test	*N*	*Min*	*Max*	*Mean*	*SD*
Pre	38	13.04	65.22	37.19	13.13
Post	38	56.52	95.65	81.12	7.38

Table 6
Wilcoxon statistical test for the TCE questionnaire

Variable	*Z*	*p*
postPPTE-prePPTE	−5.388	<.001

For the TCE knowledge questionnaire it was found that there was statistically significant difference as ($Z = -5.388$, $p < .001$) (see Table 6). Also, it was found that after the teaching intervention, the mean score of the participants ($M = 81.12$) was noticeably higher than the one before ($M = 37.19$) (see Table 5). Therefore, it can be concluded that the intervention resulted in a significant statistical and numerically large increase in their score.

6. Discussion and Conclusion

In conclusion, it was found that all the participants in this study appeared to have low to no knowledge of heat concepts before the teaching intervention. Also, from the descriptive analysis of the responses, alternative ideas emerged that are confirmed by the literature. The students' responses highlight the misunderstanding between the terms of: temperature, heat and energy. Similar results for the concepts of heat were also found by Chiou and Anderson (2009).

Poor performance on TCE questionnaire scores is likely due to the important role played by strong and hard-to-revert preexisting misconceptions. These misconceptions were formed during their early stages of education as well as from the wrong use of the terms "heat", "temperature" and "energy" in their daily life (Chu et al., 2012). For example, most of the participants consider heat as a substance that is transferred from one body to another (Question 2) (Thomaz et al., 1995). In addition, the results showed that most students consider that heat contained in a body depends on its material i.e. it is an intrinsic property (Question 14 and Question 24) (Chiou & Anderson, 2010; Chu et al., 2012). Another alternative idea prevailed among students was that temperature when water boils does not remain constant but increases (Question 5) (Adadan & Yavuzkaya, 2018).

On the other hand, after the intervention the research conducted and the active participation of the students in experimental procedures, lead the majority to improve their performance on the TCE questionnaire. This was realized by comparing the average scores before and after (scorepre = 37.18±13.12, scorepost = 81.12±7.37) the intervention. The comparison of the students' performance before and after the teaching intervention resulted in a statistically significant difference, so the average score of the participants increased to a large extent. Therefore, the didactic intervention had positive results in conceptual change and was successful. This aligns with the findings of Strat et al. (2023), whose systematic review highlights the benefits of inquiry-based science education [IBSE] in helping preservice teachers understand both science concepts and inquiry teaching methods. However, Strat et al. (2023) also pointed out that relatively few studies focus on how

IBSE impacts preservice teachers' attitudes toward science, an area where this study provides valuable insights. Moreover, successful results of inquiry-based interventions in students' misconceptions have been found for both concepts of heat (Prince et al., 2009; Prince et al., 2012; Nottis et al., 2017) and engineering (Adam et al., 2015).

Furthermore, a comparison was made of teachers' beliefs about their SE before and after the teaching intervention. It was observed that the students who actively participated in tasks and activities, evaluate the results, apply these interpretations to develop beliefs on their ability to engage in subsequent tasks and act in a way consistent with the developed beliefs (Deehan, 2017). Riegle-Crumb et al. (2015) similarly emphasize the importance of hands-on experiences in fostering positive attitudes toward science among preservice elementary teachers. Their study demonstrated that participation in inquiry-based courses significantly improved preservice teachers' confidence and enjoyment of science, while reducing anxiety—outcomes consistent with the present study's results. As noted by Kotsis (2024), hands-on experiments enable students to formulate and test hypotheses, assess data, and draw conclusions based on evidence. These processes are essential for developing critical thinking skills and a deeper understanding of scientific concepts. Most of the students had satisfactory levels of SE both before and after the course. More specifically for the PPTE subscale the comparison of mean scores showed a small increase and this difference was found to be statistically significant. Therefore, future teachers' confidence in their ability to teach science improved as in (Bhattacharyya et al., 2009; Eckhoff, 2016; Eshach, 2003). As far as the expected learning outcomes are concerned, they seem to be constant in the same levels both before and after the teaching intervention and it was not observed significant difference. Still, this difference was found not to be statistically significant (Deehan, 2017). Therefore, there was no improvement in students' self-beliefs responsible for their students' performance. Also, the PPTE scale was found to be higher than the PTOE scale, which is also found by Deehan et al. (2017).

7. Limitations and Future Research

The first limitation that arose in the present study has to do with the fact that the data involved on the study were from student responses of a closed questionnaire. Gathering additional data through interviews (so that students to be able to explain how they answer) would provide further information about the way students understand and interpret the concepts of heat. Furthermore, an additional limitation that arose during the research process is that the sample is relatively small and was only from a single university in Greece, therefore it cannot be considered representative for the whole of tertiary education in Greece. In the future, larger samples of more institutions could increase the reliability of the results.

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Appendix. Thermal Concept Evaluation Instrument

1. The temperature of ice blocks that are stored in the freezer compartment of a refrigerator would most likely to be:

a. –10°C b. 0°C c. 5° C d. It depends on the size of the ice cubes.

2. George takes six ice cubes from the freezer and puts four of them into a glass of water. He leaves two on the countertop. He stirs and stirs until the ice cubes are much smaller and have stopped melting. What is the most likely temperature of the water at this stage?

a. –10°C b. 0°C c. 5°C d. 10°C

3. The ice cubes Ken left on the counter have almost melted and are lying in a puddle of water. What is the most likely temperature of these smaller ice cubes?

a. –10°C b. 0°C c. 5° C d. 10°C

4. On the stove is a kettle full of water. The water has started to boil rapidly. The most likely temperature of the water is about:

a. 88°C b. 98°C c. 110°C d. None of the above answers could be right.

5. Five minutes later, the water in the kettle is still boiling. The most likely temperature of the water now is about:

a. 88°C b. 98°C c. 110°C d. 120°C

6. What do you think is the temperature of the steam above the boiling water in the kettle?

a. 88°C b. 98°C c. 110°C d. 120°C

7. John takes two cups of water at 40°C and mixes them with one cup of water at 10°C. What is the most likely temperature of the mixture?

a. 20°C b. 25°C c. 30°C d. 50°C

8. Jim believes he must use boiling water to make a cup of tea. He tells his friends: "I couldn't make tea if I was camping on a high mountain because water doesn't boil at high altitudes."

a. Helen says: "Yes it does, but the boiling water is just not as hot as it is here."
b. Maria says: "That's not true. Water always boils at the same temperature."
c. Panos says: "The boiling point of the water decreases, but the water itself is still at 100 degrees."
d. Nick says: "I agree with Jim. The water never gets to its boiling point."

9. Tolis takes a can of cola and a plastic bottle of cola from the refrigerator, where they have been overnight. He quickly puts a thermometer in the cola in the can. The temperature is 7°C. What are the most likely temperatures of the plastic bottle and cola it holds?

a. They are both less than 7°C.
b. They are both equal to 7°C.
c. They are both greater than 7°C.
d. The cola is at 7°C but the bottle is greater than 7°C.
e. It depends on the amount of cola and/or the size of the bottle.

10. A few minutes later, Ned picks up the cola can and then tells everyone that the countertop underneath it feels colder than the rest of the counter.

a. Thanasis says: "The cold has been transferred from the cola to the counter."
b. Georgia says: "There is no energy left in the counter beneath the can."
c. Dimitra says: "Some heat has been transferred from the counter to the cola."
d. Spiros says: "The can causes heat beneath the can to move away through the countertop."

Whose explanation do you think is best?

11. Natasa asks one group of friends: "If I put 100 grams of ice at 0° C and 100 grams of water at 0°C into a freezer, which one will eventually lose the greatest amount of heat?

a. Cathrin says: "The 100 grams of ice."
b. Vassilis says: "The 100 grams of water."
c. Nikos says: "Neither because they both contain the same amount of heat."
d. Theo says: "There's no answer, because ice doesn't contain any heat."
e. Michael says: "There's no answer, because you can't get water at 0°C."

Which of her friends do you most agree with?

12. Maria is boiling water in a saucepan on the stovetop. What do you think is in the bubbles that form in the boiling water? Mostly:

a. Air b. Oxygen and hydrogen gas
c. Water vapor d. There's nothing in the bubbles

13. After cooking some eggs in the boiling water, Mel cools the eggs by putting them into a bowl of cold water. Which of the following explains the cooling process?

a. Temperature is transferred from the eggs to the water.
b. Cold moves from the water into the eggs.
c. Hot objects naturally cool down.
d. Energy is transferred from the eggs to the water.

14. Joanna announces that she does not like sitting on the metal chairs in the room because "they are colder than the plastic ones."

a. Jim agrees and says: "They are colder because metal is naturally colder than plastic."
b. Kostas says: "They are not colder, they are at the same temperature."
c. Lucia says: "They are not colder, the metal ones just feel colder because they are heavier."
d. Mary says: "They are colder because metal has less heat to lose than plastic."

Who do you think is right?

15. A group is listening to the weather forecast on a radio. They hear: "… tonight it will be a chilly 5°C, colder than the 10°C it was last night."

a. John says: "That means it will be twice as cold tonight as it was last night."
b. Katerina says: "That's not right. 5°C is not twice as cold as 10°C."
c. Ray says: "It's partly right, but she should have said that 10°C is twice as warm as 5°C."
d. George says: "It's partly right, but she should have said that 5°C is half as cold as 10°C."

Whose statement do you most agree with?

16. Kristen takes a metal ruler and a wooden ruler from his pencil case. He announces that the metal one feels colder than the wooden one. What is your preferred explanation?

a. Metal conducts energy away from his hand more rapidly than wood.
b. Wood is a naturally warmer substance than metal.
c. The wooden ruler contains more heat than the metal ruler.
d. Metals are better heat radiators than wood.
e. Cold flows more readily from a metal

17. Antonia took two glass bottles containing water at 20°C and wrapped them in washcloths. One of the washcloths was wet and the other was dry. 20 minutes later, she measured the water temperature in each. The water in the bottle with the wet washcloth was 18°C, the water in the bottle with the dry washcloth was 22°C. The most likely room temperature during this experiment was:

a. 26°C b. 21°C c. 20°C d. 18°C

18. Dimitris simultaneously picks up two cartons of chocolate milk, a cold one from the refrigerator and a warm one that has been sitting on the countertop for some time. Why do you think the carton from the refrigerator feels colder than the one from the countertop? Compared with the warm carton, the cold carton…

a. contains more cold.
b. contains less heat.
c. is a poorer heat conductor.
d. conducts heat more rapidly from Dan's hand.
e. conducts cold more rapidly to Dan's hand.

19. Rita reckons his mother cooks soup in a pressure cooker because it cooks faster than in a normal saucepan but he doesn't know why. [Pressure cookers have a sealed lid so that the pressure inside rises well above atmospheric pressure.]

a. Eleni says: "It's because the pressure causes water to boil above 100°C."
b. Kostas says: "It's because the high pressure generates extra heat."
c. Fay says: "It's because the steam is at a higher temperature than the boiling soup."
d. Theo says: "It's because pressure cookers spread the heat more evenly through the food."

Which person do you most agree with?

20. Panos believes her dad cooks cakes on the top shelf inside the electric oven because it is hotter at the top than at the bottom.

a. Petros says that it's hotter at the top because heat rises.
b. Samuel says that it is hotter because metal trays concentrate the heat.
c. Tasos says it's hotter at the top because the hotter the air the less dense it is.
d. Tim disagrees with them all and says that it's not possible to be hotter at the top.

Which person do you think is right?

21. Bianca is reading a multiple-choice question from a textbook: "Sweating cools you down because the sweat lying on your skin:

a. wets the surface, and wet surfaces draw more heat out than dry surfaces."
b. drains heat from the pores and spreads it out over the surface of the skin."
c. is the same temperature as your skin but is evaporating and so is carrying heat away."
d. is slightly cooler than your skin because of evaporation and so heat is transferred from your skin to the sweat."

Which answer would you tell her to select?

22. When Zack uses a bicycle pump to pump up his bike tires, he notices that the pump becomes quite hot. Which explanation below seems to be the best one?

a. Energy has been transferred to the pump.
b. Temperature has been transferred to the pump.
c. Heat flows from his hands to the pump.
d. The metal in the pump causes the temperature to rise.

23. Why do we wear sweaters in cold weather?

a. To keep cold out.
b. To generate heat.
c. To reduce heat loss.
d. All three of the above reasons are correct.

24. Vassilis takes some Popsicles from the freezer, where he had placed them the day before, and tells everyone that the wooden sticks are at a higher temperature than the ice part.

a. Dimitra says: "You're right because the wooden sticks don't get as cold as ice does."
b. Iason says: "You're right because ice contains more cold than wood does."
c. Rita says: "You're wrong, they only feel different because the sticks contain more heat."
d. Anna says: "I think they are at the same temperature because they are together."

Which person do you most agree with?

25. George is describing a TV segment she saw the night before: "I saw physicists make super-conductor magnets, which were at a temperature of –260°C."

a. Joe doubts this: "You must have made a mistake. You can't have a temperature as low as that."
b. Katia disagrees: "Yes you can. There's no limit on the lowest temperature."
c. Leonidas believes he is right: "I think the magnet was near the lowest temperature possible."
d. John is not sure: "I think super-conductors are good heat conductors so you can't cool them to such a low temperature."

Who do you think is right?

26. Four students were discussing things they did as kids. The following conversation was heard: Ami: "I used to wrap my dolls in blankets but could never understand why they didn't warm up."

a. Nick replied: "It's because the blankets you used were probably poor insulators."
b. Lydia replied: "It's because the blankets you used were probably poor conductors."
c. Jared replied: "It's because the dolls were made of material which did not hold heat well."
d. Kevin replied: "It's because the dolls were made of material which took a long time to warm up."
e. Kostas replied: "You're all wrong."

Who do you agree with?

27. Three objects of the same size: a piece of plastic, a piece of wood and a piece of metal lie on the balcony for a long time on a cold day at winter. Which object feels the coldest when you touch it?

a. plastic b. woolen c. metallic d. all the above feel the same

28. Which of the above objects has the lowest temperature?

a. plastic b. woolen c. metallic d. all of them feel the same

29. If we heat the above items in an oven at 90°C for a long time. Which object will feel warmer when I touch it?

a. plastic b. woolen c. metallic d. all of them feel the same

30. Which of the above objects has the highest temperature?

a. plastic b. woolen c. metallic d. all of them feel the same