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Inquiry-based Teaching and Learning in the Context of Pre-service Teachers' Science Education

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Abstract Inquiry-based learning model relies on the idea that individuals are able to learn by researching real problems and questions. It promotes science as a way of thinking and an attitude of mind. It is a multifaceted activity that involves making observations, posing hypothesis, making experiments to test it, and giving explanations. This study is in the field of science teacher education. It was conducted to investigate pre-service primary teachers' difficulties regarding the implementation of the inquiry-based teaching. The sample consists of 74 pre-service teachers' teaching scenarios for electromagnetism; they were collected in the context of an Introductory Didactics of Science Laboratory course in which participants experienced inquiry-based teaching and learning. Content analysis of the teaching scenarios was followed in order to analyze the data. The results show that pre-service teachers have some difficulties in implementing inquiry-based teaching. Their difficulties mainly focus on the formulation of the research hypothesis and the designing of the corresponding experiment in order to test the hypothesis. The findings implied that although pre-service teachers recognize experimentation as an important part of science teaching, they had difficulties designing experiments that test particular hypotheses related to the teaching objectives. These findings contribute to the field of science teacher education, shedding light to the difficulties pre-service primary teachers have in implementing inquiry-based teaching model. Particularly, pre-service primary teachers should be offered a much bigger amount of opportunities to engage in authentic inquiries before they are ready to implement inquiry-base teaching in their classes.

Keywords Inquiry-based Teaching, Teachers' Science Education, Electromagnetism

1. Introduction

Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world [1, p.23]. Inquiry has had a role in science classrooms for about a century. In 1909, John Dewey, in an address to the American Association for the Advancement of Science, contended that science teaching gave too much emphasis to the accumulation of information and not enough to science as a way of thinking and an attitude of mind. Science is more than a body of knowledge to be learned, Dewey said, there is a process or method to learn as well [2].

The abilities and understanding of inquiry are neither developed nor used in a vacuum. Inquiry is intimately connected to scientific questions — students must inquire using what they already know, and the inquiry process must add to their knowledge. For both scientist and students, inquiry and subject matter are integral to the activity. Their scientific knowledge deepens as they develop new understandings through observing and manipulating conditions in the natural world. Regarding inquiry in science education, it is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to justify what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations [1, p. 23].

Several different instructional models have been developed that can help teachers organize and sequence inquiry-oriented learning experiences for their students. All can incorporate the essential features of inquiry. They seek to engage students in important scientific questions, give students opportunities to explore and create their own explanations, provide scientific explanations and help students connect these to their own ideas, and create opportunities for students to extend, apply, and evaluate what they have learned.

The present study follows the theoretical scheme proposed by Pedaste et al., which identifies and summarizes the core features of inquiry-based learning by means of a systematic literature and includes the following phases: orientation, conceptualization, investigation, conclusion and discussion. Some of these phases are divided into sub-phases; the conceptualization phase is divided into two sub-phases: questioning and hypothesis generation; the investigation phase is divided into three sub-phases: exploration and experimentation leading to data interpretation [3].

An extensive analysis of the conditions and constraints which might favor or hinder the implementation of inquiry-based learning has been conducted [4]. The literature revealed that in most countries, pre-service primary school teachers must be offered sufficient support if they are to overcome their general disinclination towards science and deepen their knowledge so they are in a position to use inquiry-based teaching flexibly in class [5], [6]. [7]. A key factor for the successful implementation of inquiry-based learning approaches in science classrooms is the teachers' education [7], [8], [9], [10], [11]. The literature also supports the assertion that it is not science teacher education alone that makes an inquiry-oriented teacher. One of the critical factors influencing a pre-service teacher's intentions and abilities to teach science as inquiry, is his/her complex set of personal beliefs about teaching and about science [5], [8], [12]. Moreover, pre-service teachers have a lack of knowledge on science process skills and for that reason they often fail when attempting to build a learning sequence based on inquiry [5], [10], [13], [14]. Thus, a pre-service teacher predisposed to inquiry-oriented teaching will benefit most from science teacher education: learning orientations, past experiences in schools, and experience in teaching and doing science appear to support the critical aspects of an inquiry-oriented science teacher education program [5], [14], [15]. In this line, in the context of science teacher education programs, there is a need to design inquiry-based activities that will reactivate pre-service teachers' interest in these disciplines.

This is the issue under consideration in this study, which aims to investigate the extent to which pre-service primary teachers are able to design guided, inquiry-based teaching scenarios in the context of their science education program. The present study is part of a broader research investigating pre-service teachers' ability to implement inquiry-based teaching in relation to the content knowledge [16], [17], such as electromagnetism, mechanics, etc.

2. Objectives

This research aims to investigate the extent to which pre-service primary teachers are able to design guided inquiry-based lessons and materials. The research reported here formed part of a broader Introductory Didactics of Science Laboratory Course (IDSLC). In respect of the research reported here, the questions were the following:

a). To what extent are pre-service primary teachers able to design guided inquiry-based teaching material for electromagnetism and
b). Which difficulties do pre-service primary teachers face in relation to designing guided inquiry-based teaching scenarios in the context of teaching electromagnetism.

3. Research Methodology

3.1. General Background

Fieldwork was carried out in Athens, the capital of Greece, in the Department of Primary Education at the National and Kapodistrian University of Athens during the spring semester of 2018-2019.

3.2. The Sample

The sample consisted of 74 pre-service teachers' teaching scenarios of electromagnetism, developed in the context of an Introductory Didactics of Science Laboratory Course (IDSLC). Participants were selected due to convenient access. They were divided into 3 classes of 25, 25 and 24 persons whose members worked in pairs. However, they did not have the characteristics of volunteers because they had to deliver the written report anyway in order to pass the course (IDSLC).

Regarding their scientific training and science knowledge, most of the pre-service teachers admitted into the Department choose the Humanities orientation. According to the Greek curriculum, during the last two years of secondary school, students may choose their orientation (e.g. Science, Technology, Humanities). Science classes are mandatory at every grade in secondary school, except the final year for those who choose the Humanities orientation. As for the academic background of the pre-service teachers, they attended an Introductory Physics Course (IPC) which is a second-year course. During that course, they had limited opportunities to learn science through inquiry or to conduct scientific inquiries themselves.

In the context of IDSLC pre-service teachers were asked to design inquiry-based teaching scenarios in the field of electromagnetism, photosynthesis and heat. In this paper, we focus our analysis on the teaching scenarios concerning electromagnetism, as it offers opportunities for inquiry-based teaching and is included in the syllabus of all grades in the Greek educational system.

3.3. Procedures and Instruments

The IDSLC, which is a fourth-year course, comprised of an introductory lesson and four independent two-hour laboratory exercises once a week: 1) teaching Nature of Science (NOS), 2) teaching electromagnetism, 3) teaching photosynthesis and 4) teaching heat.

The introductory lesson emphasized the "culture" of inquiry-based teaching and learning compared to other methods. The lesson focused on the necessary "theoretical framework" for designing a short inquiry in a science class, which consists of: formulation of research questions/teaching objectives, the phases of the inquiry and the different degrees of guidance the teacher may offer ranging from a "full-guided" to an "open" inquiry. In the context of the present course, we focused on guided inquiry-based teaching. Pre-service primary teachers were given examples of guided inquiries and had the opportunity to discuss on the "expected" difficulties.

During the second lesson, pre-service teachers experienced teaching and learning NOS. They participated in an explicit reflective teaching on NOS focusing on the difference between "scientific and not scientific questions" and the difference between observation, inference, and conclusion. For homework, they were asked to design a teaching scenario regarding some aspects of NOS addressing primary school students.

During the third lesson, pre-service primary teachers participated in an inquiry-oriented teaching of electromagnetism. Following the phases of the guided inquiry-based teaching, they had the role of the learners and participated in all inquiry-based activities regarding the subject: They experimentally determined the relationship between electricity and magnetism and conceptualized the working principles of electric motors and electromagnets. During the fourth and fifth lessons, preservice students participated in inquiries related to photosynthesis and heat correspondingly.

As part of their final assessment, participants were asked to develop four inquiry-based teaching scenarios, including a lesson plan and the related work sheets, which corresponded to the content knowledge of the four laboratory exercises. A lesson plan included the teaching objectives and discussed the organization of the classroom and the proposed activities according to the teaching method. Work sheets address the students and include most of the guidance the teacher wish to offer.

Regarding the research data, 74 teaching scenarios regarding electromagnetism were collected. According to the instructions, the teaching scenario was designed for a two up to four-hour teaching.

3.4. Data Analysis

Both qualitative and quantitative methods are used. Conceptual content analysis was used in order to code pre-service teachers' proposed activities. For methodological reasons related to reliability, a prior coding of the data was conducted. Subsequently, the inductive categories were established by the first three authors-coders (Cohen's kappa 0.8), adequate according to [18]. In this case, the content unit was the activities the participants enclosed in their teaching scenarios. Quantitative steps of analysis (e.g. percentages), the so-called descriptive statistics, followed in order to quantify the findings and present a clearer picture of the difficulties pre-service teachers have regarding the implementation of the Inquiry-Based Teaching [19].

The trustworthiness of this research study was checked by implementing accordant quality criteria: credibility, confirmability, dependability, and transferability. Credibility was established through peer debriefing. Peers provided feedback on the methodology of the data analysis. The approaches that researchers used to increase confirmability were documentation and control of bias, while coding agreement was another strategy used to enhance dependability. Moreover, the criterion of descriptive adequacy, one aspect of transferability, was applied. A thorough description of the context in which the IDSLC was undertaken was provided, so that readers can determine the extent to which the findings of the case being examined can be applicable to alternative settings [20].

The 74 participants have set 77 teaching objectives which were categorized according to whether they were formulated as research questions or not. A teaching objective is regarded to be a research question if it is a testable one; it is a question that correlates at least two variables or a cause and effect relationship. For example, the question *"How the temperature water boils depend on pressure?"* is a research question. Students can design and make an experiment that tests a hypothesis on how boiling temperature is affected by pressure. A teaching objective is a non-research question if it is non-testable. Usually these are the "why" questions. For example, the question "Why gravity exists?" is a non-testable question, upon which students have no hypothesis to experimentally test. After the first categorization of the teaching objectives, they were analyzed according to what extent they were inquiry-based approached and were classified in three categories: "fully inquiry-based approached", "partly inquiry-based approached", and "not at all inquiry-based approached". A teaching objective is "fully inquiry-based approached" if all five phases of the inquiry framework are implemented: orientation, hypothesis generation, experimentation, explanation, conclusion and discussion. A teaching objective is "partly inquiry-based approached" if the inquiry includes at least the hypothesis generation phase and the experimentation. Finally, a teaching objective is "not at all inquiry-based approached" if the proposed activities do not include hypothesis generation and experimentation.

The analysis, then, referred to whether the teaching objectives that had been fully, partly, or not at all inquiry-based approached were formulated as research questions or not.

At the next step, the analysis referred to whether the teaching objectives that had been fully, partly, or not at all inquiry-based were approached through a formulation of a hypothesis.

Subsequently, the analysis discussed whether the teaching objectives that had been fully, partly, or not at all inquiry-based approached included the formulation of a hypothesis that could be tested experimentally.

Thereafter, the analysis examined whether the teaching objectives that were fully, partly, or not at all inquiry-based approached, were approached through a hypothesis that was related to the particular teaching objective.

The next steps of the analysis mainly concern the position of the experiment in the inquiry-based teaching sequence. In particular, a correlation was made between the teaching objectives that were fully, partly, or not at all inquiry-based approached, and whether they contained an experiment in the engagement phase, in the hypothesis phase, in the experimentation phase, in the explanation phase or / and in the evaluation phase.

Finally, we analyzed the phases of the inquiry-based model that pre-service teachers included in their scenarios.

3.5. Limitations

Data for this research were collected from a particular Department of Primary Education (that of the National and Kapodistrian University of Athens). The inherent bias in convenience sampling [21], due to under-representation of particular subgroups in the sample, does not allow trustworthy inferences to be made about the intended population

4. Results

The content analysis revealed that pre-service teachers have certain difficulties regarding the implementation of inquiry-based teaching. Specifically:

Sixty-two out of seventy-seven (62/77) teaching objectives were formulated as a research question and fifteen out of seventy-seven (15/77) were formulated in different form.

For example, a teaching objective in the form of a research question is: *"Students will be able to determine experimentally the principle of operation of the electric generator"* (pre-service teacher 7 (PST7)) while a teaching objective which is not in the form of a research question is: *"Students will be able to describe the principle of operation of the electric generator"* (PST08 and PST59).

Regarding the relation between how an objective is approached (fully, partly, or not at all inquiry based) and the way it is formulated (as a research question or not). The results are shown in Table 1.

Table 1. Research or non-research questions as teaching objectives

		Absolute Frequency	Percentage (%)
Fully inquiry approached	Research Question	23/24	95,8
	Non-research Question	1/24	4,2
Partly inquiry approached	Research question	8/9	88,9
	Non-research question	1/9	11,1
Not at all inquiry approached	Research Question	31/44	70,5
	Non-research Question	13/44	27,3

Table 1 shows that twenty-three out of twenty-four (23/24) objectives that were fully inquiry approached were formulated as a research question. Eight out of nine (8/9) objectives that were partly inquiry approached had the form of a research question. Finally, thirty-one out of forty-four (31/44) objectives that were not inquiry approached were formulated as a research question. What we can conclude so far, is that the formulation of the teaching objective as a research question or not is not a determining factor in the implementation of the inquiry-based teaching model. It seems that although pre-service teachers can formulate a research question, they have difficulties in the implementation of the inquiry. Such difficulties are revealed below.

Regarding the analysis concerning whether the objectives were fully, partly, or not at all inquiry approached contained a hypothesis in their teaching sequence, the results are shown in Table 2.

Table 2 reveals that all objectives that were fully inquiry approached, included a hypothesis in the context of the corresponding teaching sequence. Similarly, for the objectives that were partly inquiry approached. On the contrary, most of the objectives that were not at all inquiry approached, did not contain a hypothesis. Therefore, it seems that hypothesis formulation is a considerable difficulty in implementing the inquiry-based teaching model.

Table 2. Hypothesis formulation

	Absolute frequency	Percentage (%)
Fully inquiry approached including hypothesis	24/24	100
Partly inquiry approached including hypothesis formulation	9/9	100
Not at all inquiry approached including hypothesis formulation	4/44	9,1

In addition, Table 3 reveals the relation between the objectives that were fully, partly, or not at all inquiry approached and a hypothesis that can be tested experimentally.

Table 3. Hypotheses that can be experimentally tested

	Absolute frequency	Percentages (%)
Fully inquiry approached including an experimentally testable hypothesis	20/24	83,3
Partly inquiry approached including an experimentally testable hypothesis	7/9	77,8
Not at all inquiry approached including an experimentally testable hypothesis	3/44	6,8

The majority of the objectives that were fully inquiry approached (20/24) included in the teaching sequence the formulation of an experimentally testable hypothesis. The same is for the objectives that were partly inquiry approached (7/9). Most of the objectives that were not at all inquiry approached did not include an experimentally testable hypothesis (Table 3). For example, PST9, in the context of her teaching scenario, formulated a hypothesis such as: *"What do you think will happen if we put a magnet into a coil?"*, but she bypasses the experimentation phase.

Comparing findings from Table 2 and Table 3 we can conclude that pre-service teachers found it more difficult to formulate an experimentally testable hypothesis than to formulate a hypothesis in general. Therefore, it seems that the difficulty of formulating a hypothesis that can be tested experimentally is greater than the difficulty of formulating a hypothesis in general.

In Table 4 it is presented whether the objectives were fully, partly, or not at all inquiry approached contained in their teaching sequence hypotheses that were related to them (Table 4).

Most teaching objectives that were fully inquiry approached (22/24) included a relative hypothesis, in the context of the teaching sequence. The same is for the teaching objectives that were partly inquiry approached (8/9). For example, a pre-service teacher formulated the teaching objective as follows: *"Students should experimentally find out the principle of the operation of the electric generator"* (PST35). Then, providing a picture of the inner part of a dynamo, she formulates the following hypothesis *"What do you think will happen to the light bulb if we quickly rotate the inner part?"* The difficulty here lies mainly on how to formulate the hypothesis to be experimentally tested.

Table 4. Hypotheses related to teaching objectives

	Absolute frequency	Percentage (%)
Fully inquiry approached including a hypothesis related to the teaching objective	22/24	91,7
Partly inquiry approached including a hypothesis related to the teaching objective	8/9	88,9
Not at all inquiry approached including a hypothesis related to the teaching objective	4/44	9,1

The position of the experiment in the different phases of the inquiry-based teaching model is then analyzed. Specifically, in Table 5, it is shown in which phases of the inquiry (formulation of the hypothesis, experiment, explanation, and evaluation) experiments are included.

Table 5. Using experiments in different phases of inquiry-based teaching

		Absolute frequency	Percentages (%)
Fully inquiry approached	Orientation	1/24	4,17
	Hypothesis	14/24	58,3
	Experimentation	24/24	100
	Explanation-Discussion	16/24	66,7
	Assessment	4/24	16,7
Partly inquiry approached	Orientation	2/9	22,2
	Hypothesis	4/9	44,4
	Experimentation	9/9	100
	Explanation-Discussion	6/9	66,7
	Assessment	0/9	0
Not at all inquiry approached	Orientation	3/44	6,8
	Hypothesis	1/44	2,3
	Experimentation	41/44	93,2
	Explanation-Discussion	9/44	20,5
	Assessment	3/44	6,8

Table 5 shows that the pre-service teachers who fully and partly applied the inquiry-based teaching suggested experiments not only in the experimentation phase but in hypothesis and explanation – discussion phase as well.

This finding reveals that although pre-service teachers have not difficulty proposing experiments, they have difficulty combining the proper experiment that tests a particular hypothesis.

This is also confirmed by Table 6, which shows the phases of the inquiry-based teaching model which were included by the pre-service teachers who partly or not at all followed the inquiry-based teaching model in their scenarios.

Table 6. Phases of the inquiry-based teaching included in the teaching scenarios

		Absolute frequency	Percentages
Partly inquiry approach	Orientation	4/9	44,4
	Hypothesis	9/9	100
	Experimentation	9/9	100
	Explanation – Discussion	6/9	66,7
	Assessment	2/9	22,2
Not at all inquiry approach	Orientation	25/44	56,8
	Hypothesis	3/44	6,8
	Experimentation	41/44	93,2
	Explanation – Discussion	26/44	59,1
	Assessment	21/44	47,7

Table 6 shows that all pre-service teachers were able to suggest an experimental activity in their scenarios. However, pre-service teachers who could not apply the inquiry-based teaching model at all could not formulate a relevant hypothesis. What emerges as a great difficulty in using the inquiry-based teaching model is the combination of formulating an appropriate hypothesis and proposing the appropriate experiment that tests this hypothesis.

5. Conclusions – Discussion

This research served two objectives: 1. To examine to what extent are pre-service primary teachers able to design guided inquiry-based teaching material for electromagnetism and 2. To identify the difficulties pre-service primary teachers face in relation to designing guided inquiry-based teaching scenarios in the context of teaching electromagnetism. After pre-service primary teachers participated in an IDSLC and designed their own teaching scenarios on electromagnetism, they were advised to follow the phases of the inquiry-based teaching method.

The results reveal that most pre-service teachers, participants of the present study have some difficulties in designing inquiry-based teaching scenarios. Their difficulties primarily relate to the formulation of hypothesis and the corresponding experiment that test the hypothesis [17]. Most of them have the knowledge and the ability to propose an experiment to approach their teaching objectives but they face difficulties in the formulation of the corresponding hypothesis. At the core of such difficulties lies a weak understanding of what an experiment stands for in the scientific investigation [14], [22], [23].

Therefore, the most crucial contribution of this research is the strong evidence regarding pre-service teachers' difficulties in integrating the experiment in the inquiry-based teaching. As this research shows, pre-service teachers find experimentation crucial. This is why they propose an experiment for every teaching objective. The problem lies in the weak understanding of the relation between the experiment and the testing procedure it needs to contribute to [5], [16].

Consequently, to overcome the difficulties presented here, some alternatives and future considerations are proposed. Such considerations could include more training in science process skills which could enhance pre-service teachers' knowledge and experience in participating in authentic scientific investigations [7], [9]. In other words, participating in an authentic project could support teachers' abilities to pose research questions and propose appropriate experiments in order to investigate their questions. Further research in the field could shed light on whether pre-service teachers' ability to implement the inquiry-based teaching depends on the content knowledge.

Regarding the research findings, they are limited to the sample. Therefore, research on the difficulties pre-service teachers have in designing inquiry-based teaching scenarios could be repeated to enhance the reliability of the findings.

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