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The Epistemological Perceptions of the Relationship between Physics and Mathematics and Its Effect on Problem-Solving among Pre-Service Teachers at Yarmouk University in Jordan

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Abstract

The purpose of this paper was to examine the perception pre-service teachers hold to the nature of the relationship between physics and mathematics. The study examined this relationship in reference to their performance in problem solving and strategies they used. The results of this empirical study suggested that most participants hold a naïve epistemological view that considers mathematics as an instrumental tool for learning physics. The results indicated that these views could be attributed to failure physics problem solving.

Keywords: epistemological perceptions, physics, mathematics, problem-solving, pre-service teachers

1. Introduction

Nowadays, the relationship between mathematics and physics is increasingly having prominent importance for most mathematicians and physicists. The nature of this relationship leads to a misunderstanding that is quickly passed from the teacher to his/her students. For example, the idea that mathematics is just an instrumental tool for learning physics concepts.

There are two methods to achieve the progress that enables physicists study natural phenomenon. First, the trial and observation. Second is mathematical thinking. However, the first one is considered a limited one since it involves only collecting data. Whereas, the other method enables one deduct results and conclusions not being actually experimented. It is obvious that the second method is effective and yields to creative successful learners. This by itself is due to the role mathematics plays in studying the nature system (Quale, 2011).

No doubts, the teacher is considered a cornerstone in the teaching learning process. That is, since he/she has the capability to promote students' talents and motivates them. In addition, the teacher is able to translate teaching objectives into classroom activities. In order to achieve this, teachers are required to develop their capacities in fostering students' learning, and shaping their future. However, for this specific role, they have to acquire pre-service and in-service academic and professional competencies that are essential to produce high-qualified experienced and confident teachers (Kok, 2006).

A common complain nowadays by physics teachers is that most students lack the fundamental knowledge in mathematical concepts. Moreover, it is apparent that mastering one domain of mathematical skills does not grantee success in physics. Using mathematics in physics is much more complicated than direct applications of algorithms and computations. In fact, despite deep connections between physics and mathematics, that have wide consensus among scholars, still, mathematics is largely viewed as a tool to quantify material and a way to express the relationship between them (Pospiech, 2009).

The connection between mathematics and physics is considered a premise to most educators. Many scientists affirm their inevitability between mathematics and physics learning. Such quotations are:

Many physicists have stressed the indispensable role of mathematics in physics. Among them, Galilei (1854, p. 60) who wrote "*the universe is written in mathematical language*" and Einstein (1934, p. 117) believed that *"the actual creative principle in physics lies in mathematics"*. There are many other physicists who emphasized the deep interrelation between mathematics and physics like Feynman for example who stated that *"...it is impossible to explain honestly the beauties of the laws of nature in a way that people can feel, without their* *some deep understanding of mathematics."* (Feynman, 1992)

Reflecting on such writings and recognizing the connection between material physical world and theoretical mathematical models with physical theories, one observes that those mathematical models do not have counterparts in the physical world. Still they are of great value to physics. Moreover, when the mathematical models are applied to analyze an aspect of a physical system sometimes it produces non-physical solutions that describes a physical system that is simply cannot be found in the real world. This is said to be problematic to the cognitive realism of reality in physics, since mathematical theories which describes reality in physics should not lead to such unrealistic solutions (Ataide & Greca, 2013).

Educational research shows that epistemological perceptions of students, that is- their view about knowledge and how it is constructed affects their academic learning and the way they prescribe and solve problems. For example, researchers found that in the field of mathematics, individuals who believe that knowledge is composed of pieces of facts; have genuine problems in understanding mathematical concepts, processes and epistemological perceptions to learn physics concepts (Schommer, 1990; Schommer-Aikins, 2004).

According to Redish (2005) the idea of interdependence between physics and mathematics affirmable and mathematics is the language of science in which physicists tend to blend physics theories with mathematical symbols in a way that has a profound impact on the use and interpretation of equations. Furthermore, Tzandekis (2000) clarifies that mathematics and physics are closely intertwined in two manners. First, the use of mathematical procedures in physics which indicates that mathematics is not limited to being a language of physics, but often used to determine the content and meaning of physics concepts. Second, physics concepts and arguments are utilized in enhancing mathematical thinking. This implies that physics is not limited to being an application field for mathematics and a way to provide ready-made solutions, but a field that produces ideas, strategies, and concepts to construct and develop new mathematical concepts, methods, and theories in all domains of mathematics.

Understanding philosophical trends of the nature of mathematics helps one understand the relationship between physics and mathematics. Ernest (1994) provides three philosophical trends to the nature of mathematics. First, Instrumental trend in which mathematics seen a set of facts, procedures and skills that are necessary to accomplish profitable rules and certain goals. Second, structural trends in which mathematics is viewed as a unified structure of objective knowledge. Third, social trend in which mathematics is considered as a dynamic cognitive structure and a field for innovation and human creativity. Further, it is a cultural product used on problem solving, and an endless process for explorations of knowledge, which is open to all what is new.

This strong relationship between physics and mathematics is a strong one that has taken different forms. According to Ataide and Greca (2013), the relationship has three aspects:

1) Mathematics is used to describe measurement of physical entities in the real world, and is used to interpret geometrical terminology and structures belonging to a perfect non-existing in the real-world.

2) Physics has an essential determines how the real world functions and that math is mere language to describe this reality.

3) Mathematics plays the major role and an indispensable displace in the process that leads to physical knowledge and constructing physical laws and concepts.

The French scientist Patty (1995) highlighted three aspects of mathematics which was used in the physical construction of knowledge:

1) Symmetrical model which has continuously been utilized in traditional methods.

2) Understanding of mathematics as a model reflecting reality, this is clear and apparent through Galileo's writings.

3) Understanding of mathematics as a model closely linked to the construction of theoretical physics.

Reviewing the literature, many studies have been conducted on the epistemological relationship between physics and mathematics. A number of studies show that there are difficulties that arise mainly because of certain inadequate teaching methods used by the teachers. Porter and Masiagila (2000) point out that many students do not realize the concepts that lie behind the actions. These students view mathematics as specific procedures with meaningless mechanical symbols. In their study, the researchers investigated students' understanding of concepts and procedures in calculus. The sample consisted of students in their first year studying the intermediate algebra course. Fifteen students were randomly chosen as an experimental group and eighteen students were selected as a control group. The experimental group was given writing exercises while the control group is not given tutorial exercises. Interviews were conducted with students to determine their understanding of derivatives and integration. The most common response was "I know how to perform the computations, yet I do not know what they mean".

Olatoye (2007) conducted an experimental study aimed at investigating the impact of the supply of mathematics on the student's achievement in physics, chemistry, biology and mathematics. The study showed no statistically significant difference between the groups of students who were exposed to supplementary lessons of mathematics.

Due to the repeated failures among students of physics in their first year, Symonds, Lawsun, and Robiasm (2000) conducted a study on a group of low-achieving mathematics students, which were subjected to a support program. Interviews and surveys were conducted in which the results of the study show the program promoted their joy of learning mathematics, however, was negative in terms of their confidence in studying mathematics.

Karam and Popie (2011) explored developing technical skills in mathematics to structural skills through a case study to explain the role of mathematics in physics. The execution of the study includes video tutorials by the distinguished professor of electromagnetism and relatively theory. The results showed an enhancement in four skills: mathematical translation (from physics to mathematics), interpretation (from mathematics to physics) derivation (logic/ deductive thinking), and measurement (hidden similarities).

Redish and Bing (2011) investigated how mathematics is used in physics. The students were exposed to activities ranging from problems in physics requiring algebra to quantum mechanisms. The results showed that experience in problem solving requires sophisticated mathematical skills.

Uhden and Pospich (2011) studied the difficulties that students encounter when dealing with the connection between mathematics and physics. The results showed that the physical meaning and mathematical computations are two different things. Furthermore, students encountered problems when dealing with mixed fractions. The study explained that one of the reasons behind this is the belief most students hold that mathematics is a tool.

Ataide and Greca (2013) performed a qualitative study that aimed at studying the epstimological relationship between physics and mathematics. The study reveals a statistical significant between problem solving skills and epistemological views that students hold.

Karam and Poiech (2011) explored developing technical skills in mathematics to structural skills through a case study to explain the role of mathematics in physics. The lesson plans and activities in electromagnetism and relatively theory were taped. The results showed enhancement in four skills: mathematical translation (from mathematics to physics) derivation (logic/deductive thinking), and measurement (hidden similarities).

Uhden and Pospiech (2001) studied the difficulties that students encounter when translating the relationship between mathematics and physics. Students were observed when solving tasks that were designed to show the relationship between physics and mathematics. The results showed that physics meaning and mathematical computations are two different things. Furthermore, students encountered problems when dealing with mixed fractions. The study explains that one of the reasons behind this is the view most students hold that mathematics is a tool.

Ataide and Greca (2013) performed a qualitative study that aimed at studying the epistemological relationship between physics and mathematics. The sample consisted of 22 students of physics. The study reveals a statistical significant relationship between problem solving and their epistemological view.

2. The Problem

The study of physics in high secondary school is vital in enabling students interpret many phenomena and events around them. Therefore, it is relevant to motivate students' curiosity to learn physics and meet their needs. In order to achieve this, it is important to prepare qualified teachers capable of dealing with student's inquiry, facilitating students' learning and motivating their curiosity to learn.

Two factors were derived from research related to pre-service teacher programs. First, the role and importance of mathematics in learning physics and problem solving. Second, the epistemological view for the role mathematics plays in studying physics. Many research studies such as (Pietrocola, 2002; Martinez, Lopez-Gay, & Gras-Marti, 2006; Sherin, 2006) show a significant relation between teachers' perceptions of epistemological perceptions of mathematics and physics and their interaction in teaching physics. As far as our knowledge, the literature in local and Arab world is still poor in studies related to epistemological perceptions of the nature of the relationship between mathematics and physics pre-service teachers hold.

3. Research Questions

The study aims at answering the following research questions:

1) What is the level of pre-service teachers' understanding of numbers and operations and its applications in physics?

2) What are the strategies pre-service teacher uses in solving problems?

3) What is the epistemology perception that pre-service teachers hold to the role of mathematics in physics?

4. Methodology

The participants of the study were thirty four pre-service teachers at Yarmouk University. These students were enrolled in the course “science for elementary teachers”. The course is designed to help pre-service teachers acquire foundational knowledge in natural science that is needed in teaching topics covered in primary school such as: movement, energy, electric and magnetic transformations, light, earth, and climate.

One of the researchers attended the “Electrostatic” classes as an observer. Field notes were taken on the difficulties and questions raised by students during problem solving. Data was collected through a questionnaire and evaluation activities (see Appendix 1). Furthermore, the researchers interviewed each student at the end of the course. During this interview, the researchers engaged each student in conversations about their perceptions of the relationship between mathematics and physics. In addition, the researchers asked some students to clarify their responses that were ambiguous on the questionnaire and evaluation activities. Students' responses on evaluation tasks were analyzed. The questions consisted of physical problem solving that required students use mathematics skills to solve them. Furthermore, analysis to these tasks showed students weakness points.

After reviewing a number of studies that explored the relationship between mathematics and physics (Ataide & Greca, 2013; Martinez, Lopez-Gay, & Gras-Marti, 2006). The researchers prepared interview questions related to epistemological relationship between physics and mathematics. To validate the interview questions, it was given to a number of distinguished professors of science and mathematics education. Few questions were changed based on professors' feedback. The researchers performed a pilot study in which three students outside the study sample completed the questionnaire and evaluation activities test and were then interviewed. This was helpful for the researchers to estimate the time the interview will last.

The study is limited since to pre-service teachers undertaking the course, and thus the results will be generalized to similar context. Furthermore, the results are bounded by the instruments that were developed by the researchers.

5. Data Analysis

This qualitative study was applied to pre-service teachers signing for a course in Yarmouk University “Science for elementary school teachers”. The topic of “Coulomb’s law” was chosen. The researchers analyzed all class observation notes regarding each participant the instructor and one of the researchers observed. The researchers then analyzed the interviews in which the participant's responses were classified then analyzed. Further, class activities and the strategies participants used as they solved physics problems were analyzed.

Validation of data analysis

Two methods were used to analyze interviews and validate responses to tasks:

1) Validation of the researchers with others. This was done after the researchers analyzed interviews and the evaluation activities records. A random sample of interview notes was chosen along with their responses to the activities and class observations were given to two professors in science education in order to analyze and classify their responses. The consistency was found about more than 80 % to the interview and 90% to class tasks.

2) Validation among the researchers.

The researchers reevaluated and reclassified students’ responses after a period of two months. Consistency was found about 92%.

6. Results and Discussion

Results to the first question ***“What is the level of pre-service teachers’ understanding of numbers and operations?”***

The participant’s responses were categorized into four skills. The participant was given the code “Y” to indicate an understanding to the skill and mathematical concept shown in the problem solving. The code “T” means that the participant though has completed the task; however, he/she does not show any meaning to these concepts in real situations.

Table 1. Summary of student categorization

Student	Mathematical Understanding of Operations on numbers	Most remarkable Characteristic in Problem solving	Epistemic Perception of the role of mathematics in physics
1	T	OM	Tool
2	Y	C	Tool
3	T	OM	Translator
4	T	OM	Translator
5*	Y	MR	Structure
6	T	OM	Translator
7	T	OM	Translator
8	T	OM	Translator
9	T	OM	Tool
10	T	OM	Tool
11	T	OM	Tool
12	T	OM	Tool
13	T	OM	Translator
14	T	OM	Tool
15	Y	MR	Structure
16	T	C	Translator
17	T	OM	Tool
18	T	OM	Tool
19	T	OM	Translator
20	T	OM	Tool
21	T	OM	Translator
22	Y	MR	Translator
23	T	OM	Translator
24	Y*	MR	Structure
25	T	C	Tool
26	Y	C	Tool
27	T*	OM	Tool
28	T	OM	Tool
29	T*	OM	Structure
30	T	OM	Tool
31	T*	OM	Structure
32	T	OM	Tool
33	T	OM	Tool
34	T	OM	Tool

Table 2 shows the frequency and percentage of students' according to their skills in solving problems in physics.

Table 2. Distribution of the responses of students according to their skills

Distribution of the responses of students according to their skills	Frequency	Percentage
T	28	82%
Y	6	%18

Table 2 shows that 82% of participants were able to perform the tasks, however, they have no meaning to the concepts. In contrast only 18% of participants showed an understanding to the skills and concepts they applied in the problem solving task.

Results to the second question ***"What are the strategies that pre-service teachers use in solving problems?***

The participants' responses were classified into three groups based on the strategies they used in solving problems.

Operational Mathematics (OM) this includes responses that utilize mathematics as a tool and tend to solve problems using strategies like trial and error.

Conceptualization (C). Are responses that tend to prefer understanding concepts and try, though not always successful, to connect concepts with problem solving.

Mathematical Reasoning (MR) includes responses that utilize mathematical reasoning and justification to problem solving. Though not always successful in applying the mathematical procedures.

The results for the students' strategies used in problem solving can be seen in Table 3.

Table 3. Distribution of students' responses according to the strategies they used to solve problems

The strategies they used to solve problems	Frequency	Percentage
OM	26	76%
C	4	12%
MR	4	12%

Table 3 shows that 26 students tend to solve physics problems using trial and error strategy and have encountered many difficulties as they were solving the problems. Further, their solutions tend to be ambiguous. However, four of them had connected mathematical concepts to problem solving. In particular, they were participants # 2, 16, 25, 26. Furthermore, four students had utilized mathematical reasoning while solving the problems. They included valid justifications to verify their steps in solving problems. In particular, these students are (5, 15, 22, 24). Further, these students had shown evidence of acquiring the foundational knowledge in mathematics necessary to physics concepts. These students view mathematics as a structural base to physical concepts. That result is consistent with Reish and Bing (2011) who studied the relationship between mathematics in learning physics. It was found that fluency in solving problems in physics requires acquiring proficient mathematical skills. Further, the study had attributed failure in solving physics problems to the failure of utilizing mathematical concepts in physics. In addition, Ataide and Greca (2013) found a significant relationship between students' perception to the relationship between mathematics and physics and their performance in problem solving**.**

Results to question three ***"What is the epistemology perception that pre-service teachers hold to the role of mathematics in physics?"***

To answer this question, students were categorized into three groups based on their responses to the questionnaire.

Tool: mathematics is used by students to facilitate numerical calculations.

Translator: mathematics is considered a translator of physical ideas.

Structure: mathematics is considered a fundamental basis for physics.

The results are shown for these groups in the third column in the Table 1.

The results for the students' epistemological perceptions used in problem solving can be seen in Table 4.

Table 4. Distribution of the responses of the participants in accordance with the epistemological perceptions of the role of mathematics in physics

The epistemological perceptions of the role of mathematics in physics	Frequency	Percentage
Tool	18	53%
Translator	11	32%
Structure	5	15%

Table 4 shows the distribution of participants based on their epistemological perception of the role of mathematics in physics. One could notice that 53% of students hold an epistemological view that mathematics is a tool to understanding physics. Participant #1 have expressed “mathematics is the road map to solving physical equations” whereas, participant #33 said “most problems requires computations like multiplication, division,” This is consistent with findings of Uhden and Pospiech (2011) that mathematics computations and physical concepts are two different things. Further, students encounter problems when dealing with mixed fractions. They explained that one of the reasons might be due to student's perception that mathematics is a tool.

Our results show that 32% of participants view mathematics as a translator to physical thoughts. Participant #1 stated that “mathematics is an integrated field to physics”. In addition, participant # 3 declared that “mathematics is a very important field since it is an integral field to physics, it is the foundation base that holds physics”

The results show that only 15% of participants view mathematics as a structure to physics thought. Participant #5 “mathematics has a huge role, without it we could not have derived any physical laws or procedures”. This was also pointed out by Karam, Pospiech, and Pietrocola (2011) that one of the most important abilities to deal with phenomena in physics domain is to be able to use mathematics as a reasoning instrument. Further, this is consistent with what Tzanakis (2000) who pointed out that mathematics and physics are intertwined. That is mathematics is not only a language to physics, but a structure that provides ideas, concepts and methods to construct and develop many innovative mathematical theories.

7. Implications

Our study shows that students in general have failed to reflect fully the scientific concept. Despite that they may have learnt about these concepts throughout their formal middle school education and seem to have little difficulties applying mathematical notations and procedures. This failure was noticed from observation, interviews, and students responses to activities. As observed by Karam and Pietrocola (2009), the roots to this failure are that students fail to relate mathematics models to problems in physics. Furthermore, technical skills are not enough to be able to solve problems.

For learning to be effective, and to deeply understand mathematics and physical concepts, students need to relate mathematical formalization to the construction of physical concepts (Ataide & Greca, 2013).

The main finding in this current study is that a strong relationship between student's problem solving strategy, and their epistemological perception to the role mathematics plays in physics, learning and understanding physics, and solving problems in physics. This is significant in science education in general and in learning physics. Furthermore, it can influence how students face the solving physics tasks.

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Appendix A

Determining difficulties and students' epistemological perception Questionnaire.

Dear student: This questionnaire consists of questions related to the difficulties you encountered while studying the unit (Static Electricity) and your views to the role mathematics plays in solving physics problems.

(1) What are the main difficulties you encountered while studying Coulombs Law?

(2) 2-Using your own words, give your interpretations of the following physics concepts:

- Quantization of charge
- Static electricity
- Electric force
- Charge
- Electrification

(3) Write the mathematical formula that represents Coulomb's law, then express the verbal definition of it? What does the sign "=" mean to you?

(4) Show the mathematical relationships among variables included in Coulombs law.

(5) Show the mathematical relationships among variables included in Coulombs law.

(6) Which fundamental mathematical operations that you need to comprehend and apply Coulombs law? Do you feel these concepts make sense to you? Justify your answer.

(7) Have you encountered any difficulties or obstacles as you were applying the mathematical concepts that is related to numbers (exponents, multiplication, reciprocals,…) while applying solving problems related to Coulombs law?

(8) While solving physics problems, do you focus on physics concepts or mathematical concepts?

(9) In your opinion, what is the role of mathematical in physics?

Appendix B

Evaluation Activities

Dear student: Answer all of the following problems related to static electricity (Coulombs law).

(1) Describe the concept of electrical energy, from a microscopic point of view and then from a macroscopic point of view. What is the relationship between these two views?

(1) Define and explain the following:

- Connectors
- Semi-connectors
- Insulators

(2) Answer the following based on Coulombs law:

- What is the principle that Coulombs law is derived from?
- What is the relationship between force, amount of charge, and distance between them?

(3) What is the effective force between two charge particles if one is 10^{-4} other one is 25×10^{-4} coulombs, nothing lies between them, and the distance between them is 50cm?

(4) The distance between two equivalent charge particles is 0.1 m, what is the amount of charge, if the Coulombs force size is 36×10^{-5} newton.

(5) Draw a model that demonstrates the direction of the electric charge between two charge particles in the following cases:

- Two negative charges.
- Two positive charges.
- One positive charge and another negative charge.