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Interpretation of an Energy Graph for a Mass-Spring System by Prospective Science and Mathematics Teachers: A Comparison

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Abstract

This study aimed at the investigation of skills of prospective science and mathematics teachers' reading of two parabolic line graphs related to simple harmonic motion of a mass attached to a spring. The participants were 31 prospective mathematics and 20 prospective science teachers taking the General Physics II course in the second term of the teacher training program. The participants were expected to determine the type, potential or kinetic, of energy and explain the variation of these energies in a written exam. Although harmonic motion is a phenomenon in science, findings showed that prospective teachers of mathematics performed better than prospective science teachers in general. The numbers of prospective science teachers' answers about the energy types represented by the curves were wrong but the energy changes of the curves were right, was higher than the number of corresponding prospective mathematics teachers, although the reverse was expected. It is concluded that a considerable number of prospective teachers' ability to read graphs was not at the desired level and need to be improved. This study showed that graph interpretation in physics was not just related to mathematics and a successful graph usage generally requires domain specific knowledge. It can be said that the use of graph interpretation questions in an assessment tool will contribute to determining the level of understanding the related subject in addition to the development of graph related skills of learners.

INTRODUCTION

Graphs are central to the representation in natural sciences, and graphing is a key component of high level thinking activities within mathematics and science education (Roth & Bowen, 2001). They are commonly used in textbooks and educational sources and can help students understand scientific concepts and data (Glazer, 2011; Lowe, 2000; Norman, 2012; Shah & Hoeffner, 2002). Drawing, reading and interpreting graphs are integral parts of experimentation (Mckenzie & Padilla, 1986; Susac, Bubic, Kazotti, Planinic & Palmovic, 2018). However, as many experienced teachers are aware, creating graphs and interpreting them are skills that are not easily acquired by most students (Padilla, McKenzie & Shaw, 1986) and that this issue has been a subject of several educational studies in physics (Beichner, 1994; Brassel & Rowe, 1993; McDermott et al., 1987). McDermott et al. (1987) reported that students have difficulties in discriminating the slope and height of a graph and interpreting changes in height and slope. Brassel and Rowe (1993) wrote that at least one fifth of the students had difficulties linking the graph to the verbal descriptions of a given event, and they did not understand graphs as a means of representing relationships among variables. Beichner (1994) pointed out that the most common mistakes students make with kinematics graphs are that they are thinking of a graph as a picture of the situation and confusing the meaning of the slope of the line with the height of a point on the line.

Graphs were first introduced into mathematics and then into other sciences. Both physics and mathematics require students to be able to extract various pieces of information from graphs. Physics, in addition, also requires an interpretation of the obtained information in the context of given physical situation (Planinic, Milin-Sipus, Katic, Susac & Ivanjek, 2012) via transferring knowledge between mathematics and physics (Planinic, Ivanjek, Susac & Milin-Sipus, 2013). In order to make such transfer to take place, it is necessary, but not always sufficient, for students to possess the underlying mathematical knowledge (Christensen & Thompson, 2012; Nguyen & Rebello, 2011). But students' problems with mathematics may not be the only or even the main reason for students' difficulties with graphs in physics. For example, Planinic et al. (2012) showed that many high school students successfully solved the mathematical questions but were unable to answer parallel physics questions, or used different strategies for solving analogous mathematics and physics problems contrary to the prevalent belief of physics teachers. The main source of student difficulties with the concept of line graph slope in physics was not their lack of mathematical knowledge, but rather their lack of ability to interpret the slope of line graphs in physics context. Similarly, in the work of Woolnough (2000), most secondary students, even those who do well in mathematics and physics, did not make substantial links between the two domains, and they continued to demonstrate a resistance to applying their mathematical knowledge to physics.

Purpose of Study

The ability to interpret graphs is considered one of the important outcomes of high school mathematics, physics, and university instructors assume that this ability of students is fully developed by the time they enroll at the university (Planinic et al., 2013). However, several studies in physics education showed that students at university level still have deficiencies in graph interpretation skills (Araujo, Veit & Moreira, 2008; Chabalengula, Mumba & Mbewe, 2012; Foster, 2004; Ivanjek, Planinic, Hopf & Susac, 2017; Harsh & Schmitt-Harsh, 2016; Planinic, Susac, Ivanjek & Šipuš, 2019) and science teachers rarely teach about graphical techniques needed in science (Aydın & Trakçı, 2018; Jarman et al. 2012; Lai et al., 2016). To help prospective teachers in developing these skills, science and mathematics teachers and educators need to foster graph drawing and interpreting in classroom activities (Bowen & Roth, 2005; Glazer, 2011), and more research needs to be done on graphical literacy in the context of science as well as in mathematics (Glazer, 2011; Keller, 2008). Research focusing on subject-specific graph work is generally on the subjects of force, motion (Yeltekin, 2020), kinematics (Aydın & Trakçı, 2018; Phage, Lemmer, & Hitge, 2017; Sokolowski, 2017; Uyanık, 2007), heat and temperature (Aydın, 2018). As is known, periodic motion is a special and relatively difficult type of motion, taking place at later chapters of coursebooks. A number of physical systems display mechanical, electrical or magnetic vibrations, some being harmonic and some inharmonic. The most common examples of mechanical vibrations are the pendulum and the mass attached to a spring. In this study the simplest system of mass and spring and the associated energy graphs are selected to investigate the skills of prospective science and mathematics teachers related to the given energy graphs.

METHOD

Study Design

This research employed the case study method incorporating an open-ended test involving graph interpretation questions. The participants of the study were 51 prospective teachers, 31 majoring in mathematics and 20 in science, who were taking the General Physics II course in the second academic term of the teacher training program. Prospective mathematics teachers (M_1, M_2, M_3,….M_{31}) previously took this course taught by another lecturer and were now repeating the course. Prospective science teachers (S_1, S_2, S_3….S_{20}) taking the course for the first time followed the lectures almost continuously unlike their mathematics counterparts. To examine prospective teachers' graph interpretations, three questions about the two curves of a graph including knowledge of both mathematics and physics were designed. The related graphs are included in standard elementary physics textbooks at university level (i.e. Serway & Beichner, 2000) and were explained by the instructor during course work.

Data Collection

To investigate the graph interpretations of prospective teachers, line graphs displaying the relationship between two continuous variables in pictorial form were chosen here for their importance in mathematics and science education (McKenzie & Padilla, 1986; Keller, 2008). Although the mechanical set up producing simple harmonic motion is simple, the related mathematical expressions and energy graphs are somewhat complicated. First of all, curved lines may seem more difficult to interpret than straight lines (Phage, Lemmer, & Hitge, 2017), secondly plotting the two curves with only limited segments without their asymptotic extensions may pose difficulty to assess that the curves are parabolic.

Because multiple-choice questions are not a valid measure of graphing abilities (Berg & Smith, 1994), the participants were expected to explain the graph (Figure1) showing the variation of potential and kinetic energy in written exam following the teaching of harmonic motion within the scope of General Physics II course.

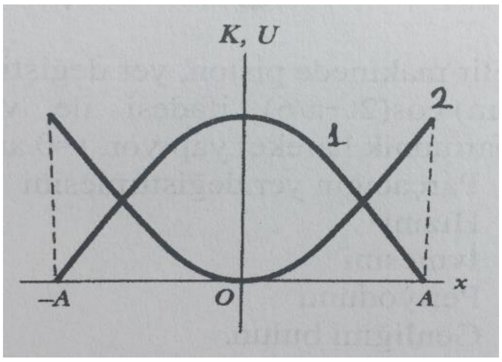

Figure 1. Graph of displacement-energy representing the harmonic motion of a mass *m* attached to a spring.

Prospective teachers should answer the following question:
a) Energy type represented by Curve 1………………….
b) Energy type represented by Curve 2 ……………………..
c) According to the graph, does the energy in a), i) increase, ii) decrease, iii) remain unchanged, as the mass moves from x= -A to x=0?
d) According to the graph, does the energy in b), i) increase, ii) decrease, iii) remain unchanged, as the mass moves from x= -A to x=0?

While the questions (a) and (b) are about the types of energy, (c) and (d) deal with the changes in these energies.

Data Analysis

The answers given by the students were analyzed according to the scale below, which was developed by Abraham et al. (1994):

0: Blank, repeats question; irrelevant or unclear response,
1: Scientifically incorrect responses containing illogical or incorrect information,
2: Responses containing some components of the scientifically accepted response,
3: Responses containing all components of the scientifically accepted response.

Then these scales were categorized in five levels as follows. The first two columns in each category show the scores from the items (a) and (b) and the second two columns show the scores from the items (c) and (d).

Table 1. Categorization of Answers of Prospective Teachers

Categories	A				B				C				D			
Score Type 1	3	3	3	3	3	3	3	1	1	1	3	3	1	1	1	1
Score Type 2					3	3	1	3					0	0	0	0
Score Type 3					3	3	1	1					1	1	3	1

Category A in which both energy types are expressed correctly and identification of the curves showing energy changes are correct
Category B in which energy types are expressed correctly but one or two identifications of the curves showing energy changes are incorrect.
Category C in which energy types are expressed incorrectly but identification of the curves showing energy changes are correct.
Category D in which both energy types are expressed incorrectly and identification of the curves showing energy changes are incorrect.
For the trustworthiness of the data collection tool, the opinions of an expert with a PhD degree were taken and conducted under the supervision of the course instructor. Although only one data collection instrument, the final exam, was used, it was assumed that the participants reflected their knowledge objectively.

FINDINGS

Table 2 shows findings obtained from the analysis of answers supplied by prospective teachers of science and mathematics.

Table 2. Categories of the answers given by prospective teachers

Prospective Science Teachers				Prospective Mathematics Teachers			
A	B	C	D	A	B	C	D
S_1, S_2 S_3, S_4 S_5, S_{20}	S_6 S_7 S_8	S_9, S_{10} S_{11}, S_{16} S_{18}	S_{12}, S_{13} S_{14}, S_{15} S_{17}, S_{18}	M_1, M_8, M_9, M_{10}, M_{12}, M_{14}, M_{18}, M_{20}, M_{21}, M_{22}, M_{24}, M_{28}, M_{31}	M_4, M_6, M_7, M_{13}, M_{15}, M_{23}, M_{30},	M_5, M_{16} M_{17}, M_{26}	M_2, M_3, M_{11}, M_{19}, M_{25}, M_{27} M_{29}
%30	%15	%25	%30	% 42	%23	%13	%22

*M: Prospective Mathematic Teachers; S: Prospective Science Teachers

According to the table, the number of prospective mathematics teachers at category A is higher than that of prospective science teachers. While nearly half of the prospective

mathematics teachers knew the graph showing the type and change of energies, the corresponding ratio is about 30% for science teachers.
When categories A and B are evaluated together, it is seen that 63% of prospective mathematics teachers and 45% of prospective science teachers correctly answered the type of energy shown in the graph.

In category B, in which energy types are expressed correctly but one or two of the curves showing energy changes are incorrect, the majority being in potential energy type. Six prospective teachers, M_4, M_{13}, M_{15}, M_{30}, S_6, and S_7, stated that as the mass moved from point -A to point 0 the potential energy increased even though it was approaching zero.

It is seen that the number of prospective science teachers in category C, in which energy types are expressed incorrectly but curves showing energy changes are given correctly, is higher than the number for mathematics teachers. Although the prospective teachers in this category did not answer the energy types correctly, they correctly expressed the changes indicated by the two curves of the graph.

Similarly, it is seen that the number of prospective science teachers in category D which represents prospective teachers who left the questions unanswered or gave wrong answers is higher than that of the prospective mathematics teacher.

CONCLUSIONS, DISCUSSION AND SUGGESTIONS

The purpose of this work was to examine the skills of prospective science and mathematics teachers in reading and understanding of two curves, combined in a single graph, related to simple harmonic motion. The comparison of the two disciplines showed some variations which permites the definition of four categories A, B, C and D. For example, although harmonic motion is a phenomenon in science, our findings about the categories A and B showed that the prospective teachers of mathematics were in general better in answering our questions than the prospective teachers of science, contrary to Dyke and White (2004) stating that prospective mathematics teachers had little willingness to use graphs as they required higher abstract thinking skills.

In category C, where the answers about the energy types represented by the curves are wrong but the energy changes represented are right, the number of prospective science teachers is higher than the number of prospective mathematics teachers, although the reverse is expected. While the prospective science teachers in this category were able to interpret the change in energy, they were not able to tell the type of energy represented by each curve. It seems that their lack of knowledge about velocity or acceleration at points A prevented them from identifying the curves representing two types of energy. This complies with the claims that although graphing is a generalizable skill used throughout many academic domains, successful graph interpretation generally requires domain specific knowledge (Boote, 2014) and the role of content knowledge on graph interpretation has largely been ignored in related research (Keller, 2008). Similarly, in some other studies (Woolnough, 2000; Ataide & Greca, 2013; Plannic et al. 2012; Plannic et al. 2013), it was expressed that the difficulties with graphs in physics were not just related to mathematics, but there at the same time were substantial links between the two domains.

The percentages of answers (15-23%) of the participants in category B in which energy types were expressed correctly but identifications of curves showing energy changes were incorrect pointed out that subject knowledge on harmonic motion did not guarantee successful graph interpretation, a result similar to that by Bowen and Roth (2005). Wrong answers in category B on the potential energy curve pointed to inadequacies in mathematical knowledge of prospective mathematics teachers.

The percentages (20-30%) of participants in category D suggest that prospective teachers need more experience in graph reading and interpretation practice in realistic applications (Roth, 1996; Bowen & Roth, 2005). It is concluded that a considerable number of prospective teachers' ability to read graphs was not at the desired level and need to be enhanced, as also emphasized in other studies (Gheith & Aljaberi, 2015). Although the prospective teachers of mathematics did not follow the Physics II course, they performed better graph reading than the prospective teachers of science who attended most of the lectures but, according to Table 2, displayed insufficient subject matter knowledge on harmonic motion of a mass-spring system. It can be said that the use of graph interpretation questions in an assessment tool will contribute to determining the level of understanding the related subject by learners in addition to the development of skills about graphs. Since graphs have generally been used in presenting the subject matter, their usage for assessment purposes has been insufficient or neglected (Gültekin & Nakipoğlu, 2015). In addition, many tests used for different examinations in the fields of science and mathematics employ graphs require skills of graph interpretation (Coleman et al., 2011). For this reason, the use of graph questions for assessment purposes is recommended to improve the awareness of student difficulties in graph handling and its importance in conceptual understanding of the subject. In this way, prospective teachers are expected to be engaged more effectively in graphical representations and relevant practices with their future students (Glazer, 2011; Marsh, 2020).

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