Robotics in physics education: fostering graphing abilities in kinematics

Dimitris Alimisis[1] and George Boulougaris[2]

[1] European Lab for Educational Technology, Sparta, Greece alimisis@otenet.gr

[2] Secondary School Education, Sparta, Greece gboulougar@sch.gr

Abstract. This paper reports a robotics-based learning experiement that took place in a school physics class (20 students aged 15). The students worked in groups to construct a robotic vehicle using Lego Mindstorms NXT kit, and then they programmed it to move in linear way first at constant speed, then at constant acceleration and deceleration. Position-time data from each experiement was logged and graphs were produced by the students using Lego Education data logging tool. The students had already been taught kinematics in a traditional lecture-based way before the experiement and their graphing abilities in kinematics were tested before and after the experiement using a special paper and pencil test. Post-test scores were found significantly higher than pre-test ones providing evidence of a positive learning impact.

Keywords: educational robotics, learning, physics, graphs

1 Introduction

The visualization of the relation between two physical quantities through a graph is a commonly used tool in physics education. Students in physics courses have to become able to draw and interpret graphs in terms of the underlying physics quantities and the relations between them. The graphing ability is considered essential for understanding physics concepts and phenomena, and one of the main skills that school physics courses are aimed to develop [1] connected by other researchers with the development of logical thinking structures [2]. In this sense, the benefits of using graphs in a physics course go beyond the specific topic covered. On the other hand, lack of graphing skills is considered a handicap and a limiting factor for learning physics [1].

However, research in physics education has identified serious difficulties that students encounter in drawing and interpreting graphs; especially in the field of kinematics students find often hard to making connections between graphs, motion concepts and the real world [1]. Moreover, other studies have shown that students often come off traditional physics courses with many kinematics misconceptions [1], [3], [4].

To cope with these problems research in physics education has suggested several technological tools (video, multimedia, modeling software and more) to support students' understanding in kinematics and the development of graphing skills through

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 2-10

dynamic visualizations [5], [6]. The Microcomputer-Based Lab (MBL) was introduced in 90's offering detection of moving objects and position-time graphs plotted on screen in real time [7]. The MBL approach was advantageous in the sense students could observe the motion event concurrently with its graphical visualization which is considered as helpful for connecting abstract motion concepts with concrete kinesthetic experiences [8]. On the other hand in the MBL approach the graph is offered as ready-made by the device not allowing learners to engineer and control the graphing process. In addition to this, learners have not much control on the motion event and the learning approach is mostly dominated by the guided discovery learning model.

Computer simulations and modeling software have also been successfully introduced in school physics teaching including kinematics [9], [10]. For example the "Graphs and Tracks" ready-to-run model based on an earlier program by David Trowbridge [11] can show position, velocity, acceleration, and energy graphs and can be used for motion-to-graphs exercises [12]. However, computer-based models and simulations have some clear limitations; they work on a virtual environment and can offer only two-dimension scenario where the moving object behaves as a "virtual perfect robot"; its behaviour is a poor iconic representation of real behaviours lacking the side effects (e.g. friction) existing in motions happening in the real world.

Educational robotic technologies have appeared in the last decade as a novel approach promising to offer and extend the benefits introduced by MBL and simulations without their limitations or deficiencies. The use of robotic technologies in education opens a new and unexplored real world environment in which subjects such as physics can be taught in a natural way [13]. Differently from a simulated environment, in educational robotics, thanks to the embodied nature of a robot, students can learn experimenting in the natural 3D real world in an explorable and measurable setting [14].

Robotics is also advantageous compared to MBL and simulations in the sense that educational robots can be designed and constructed by learners themselves from scratch. It means that a robotics-based learning environment is more engaging for students, it fosters motivation and situational interest, offers opportunities for deeper exploration and facilitates understanding of the underlying scientific concepts [15], [16]. Especially in kinematics, students can program their robots to move as they wish and produce the proper position-time graphs. As a result, the robotics-based learning can depart from guided discovery models and turn into an open, transparent activity fully controlled by learners and thus to approach the constructivism/constructionism paradigm [17].

In this framework, a learning experiement in a school class was designed to examine the impact of a constructivist robotics activity on students' graphing skills in connection with the underlying kinematics concepts related to motions at constant speed, accelerated and decelerated ones. The theme-based curriculum approach, one of the main approaches to Educational Robotics reported in the literature [18], was chosen where curriculum areas are integrated around a special topic for learning and studied mostly through inquiry and communication. The paper reports the implementation and the evaluation of the experiement; it is organized in 4 sections: section 2 describes the robotic activity, section 3 presents the evaluation methodology and results and finally section 4 reports the conclusions of this work.

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 2-10

2 The robotic activity

Based on the above mentioned theoretical framework, a constructivist approach was designed. Students had to work collaboratively in groups of 5 to construct robotic vehicles from scratch using the Lego Mindstorms NXT kit. Then they had to program their robots, using the Lego Education Programming software, to move forward and backwards in linear motion at constant speed, acceleration or deceleration. None guidance was provided by the teacher, just the necessary technical support, for example how to use the programming blocks or how to make data logging and position-time graphs. Worksheets were handed to students presenting open questions/problems and offering technical support. For example: "devise a program that will make your car to move backwards…", "make your car to move in a linear constantly accelerated motion, write down your ideas…", "can you add some more seconds of decelerated motion? How does the graph change now?"

Through this approach students could explore the real motion phenomenon while at the same time could observe the visualization of the motion in the form of a position-time graph and a table of data. This resulted in real-time multiple representations of the motion event which are considered advantageous for students' learning [19].

One class of 20 students aged 15, who had already been taught kinematics in lecture for 12 teaching hours 3 months ago, was involved in the robotic activity in 4 groups of 5. The activity took place at the 1st Lyceum of Sparta, Greece (public school of upper secondary education) in April 2013 in 4 weekly sessions of 2 hours each.

More specifically, in the 1st session each group constructed from scratch a robotic 4 wheeled vehicle with one motor using the Lego Mindstorms NXT kit. Due to the absence of other requirements or guidance, different robots were constructed by each group (fig. 1 & 2).

Fig. 1. A group of students constructing their robot (left) and posing proud of it (right)

In the 2nd session the students learned to program their robot to move forward and backward in linear motion using the Lego Education programming environment. Changing the schedule of the session, the students decided to use their robots in an improvised car-racing. Their excitement with the game of racing introduced in the learning activities some fun and motivated the students to make improvements and interventions in their vehicles to make them faster and more competitive, turning the educational session into a fun activity (fig. 2).

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 2-10

Fig. 2. Car-racing (left) and one of the students' robots (right)

In the 3rd session, physics emerged in the front stage; the students were reminded through their worksheets the basics of motion at constant speed and were asked to program their robot to move forward and then backward at constant speed. They were instructed to assemble a distance sensor on their robot in order to detect the distance from a stable object (the closest wall). They were also helped to activate the data logging tool in order to create the position-time graph on their screen. Finally they were encouraged to experiement with the power of the motor trying out different values and to observ**e** the effect on the speed of their vehicle each time (fig. 3).

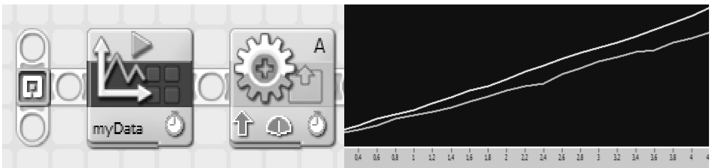


Fig. 3 Students' indicative programming solution and graph for linear motion at constant speed and position-time graph with 2 different speeds.

In the 4th session, the concept of acceleration/deceleration was reminded shortly in worksheets. The students were instructed to use the Loop block to repeat sequences of code and the Math block to perform simple arithmetic operations (addition, subtraction, multiplication, and division). Then they were asked to program their robot to perform a linear motion at constant acceleration, to create again position-time graphs and to study them carefully (fig. 4). After this, they were asked to do the same task but now at constant deceleration (fig. 5) and finally they were challenged to produce a complex motion first accelerated then decelerated (fig. 6).

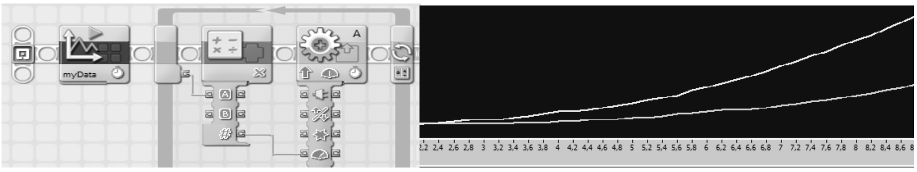


Fig.**4** Students' indicative programming solution and graph for accelerated motion with 2 different values of acceleration

Proceedings of 4th International Workshop Teaching Robotics, Teaching with Robotics &
5th International Conference Robotics in Education
Padova (Italy) July 18, 2014
ISBN 978-88-95872-06-3
pp. 2-10

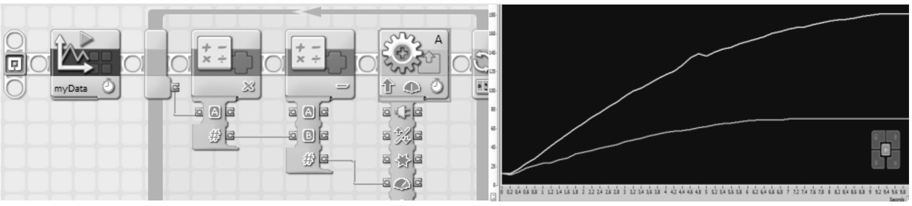


Fig.5 Students' indicative programming solution and graph for decelerated motion with 2 different values of deceleration

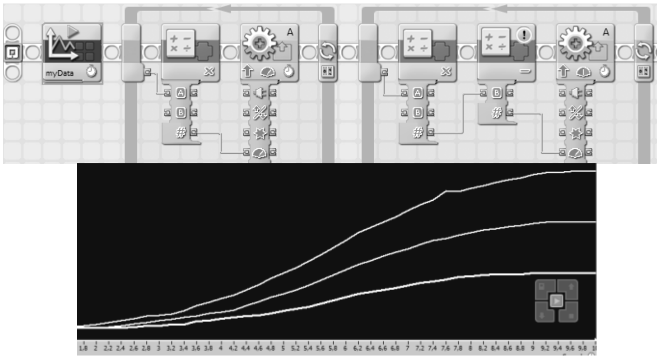


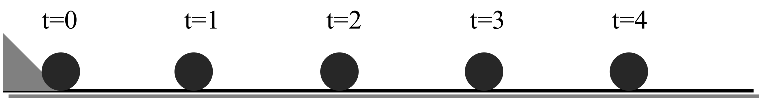
Fig. 6 Students' indicative programming solution and graph for accelerated motion followed by decelerated motion with 3 different values of acceleration/deceleration

3 Evaluation

In physics education research there has been a concern that the methodology and instrumentation used to assess graphing abilities and the impact of relevant laboratories on students' graphing abilities using multiple-choice instruments appears to have significant validity problems. The evidence from the research has identified numerous disparities between the results of multiple-choice and free-response instruments [20]. In line with this critique, we decided to use free-response paper and pencil tasks for students both before and in the end of the above 4 sessions. The test included 5 problems, same for the pre- and post-test. The problems are representative of the relevant literature and have been used in physics education research in the past [1].

The 5 problems are presented shortly below:

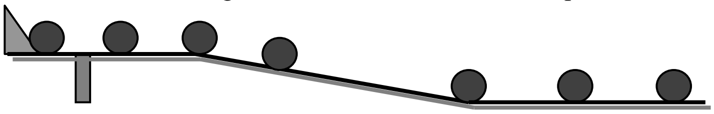
Problem 1: the ball is moving at constant speed; draw the position-time graph.



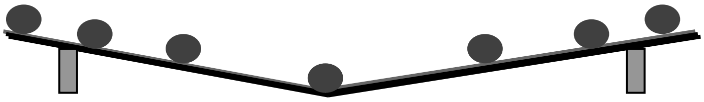
Problem 2: imagine you walk at constant speed straight to the opposite wall and come back, draw your position-time graph.

ISBN 978-88-95872-06-3

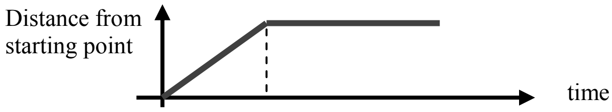
Problem 3: the ball is moving as the sketch shows; draw the position-time graph.



Problem 4: the ball is moving as the sketch shows; draw the position-time graph.



Problem 5: Explain the motion represented in the below position-time graph.



16 from the 20 students took both tests. Their answers in the pre- and post-test were recorded in a spreadsheet. Value 1 was assigned for each successful answer, 0 for unsuccessful, so the minimum score per student was 0 and the maximum was 5. Pre- and post-test score in each question/problem was defined as the count number of successful answers (fig. 7).

A statistical analysis was conducted employing a Paired Samples Test to check the significance of the observed differences between the pre- and post-test scores for each problem (table 1) and for the mean total scores (table 2). Data shows (table 1) that although students had been taught kinematics (in lecture) 3 months ago, the pre-test score was high only in the 1st problem (making graph for a simple motion at constant speed) and in less extent in the 5th problem (interpreting graph of motion at constant speed followed by stopping).

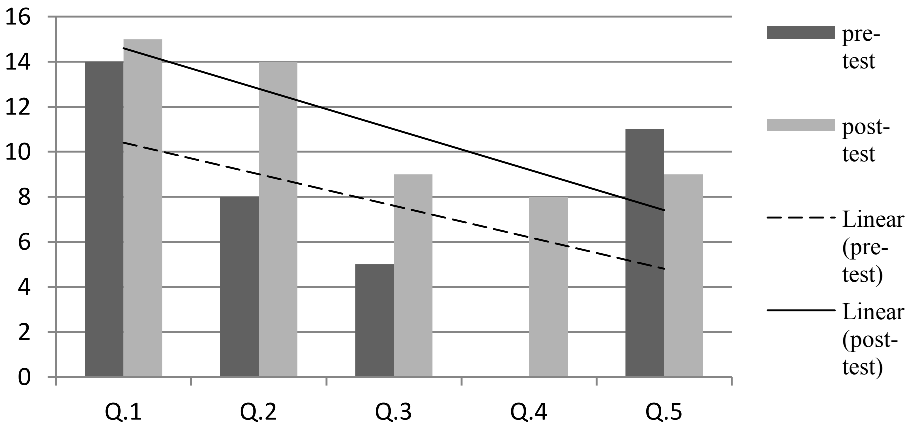


Fig. 7. Pre- and post-test scores per question

The scores in the other 3 problems were rather low; only half of the students could transform in graph the verbal description of the forward and backward motion at constant speed (problem 2); even worse were the results in problem 3 where only

31% of students succeeded in “translating” the sketch of a complex motion (at constant speed, then accelerated and again at constant speed) in position-time graph (problem 3); none drew the right graph for the complex motion (first accelerated, then decelerated) in problem 4.

Table 1. Paired samples test: students’ scores per problem in pre- and post-test (N=16)

Problem	Pre-test scores	Post test scores	t-test	df	Significance (2-tailed)
1	14 (88%)	15 (94%)	0.565	15	0,580
2	08 (50%)	14 (88%)	3.000	15	0,009
3	05 (31%)	09 (56%)	2,236	15	0,041
4	00 (00%)	08 (50%)	3,873	15	0,002
5	11 (69%)	09 (56%)	-1,000	15	0,333

After the robotic activity the scores became significantly higher in the problems 2, 3 and 4 (table 1). The improvement was more impressive in problem 4 which had been initially shown the more difficult for the students, may be due to the complexity of the combined accelerated and decelerated motion. It seems that the robotic activity has helped at least half of the students to make the right graph for this complex motion event. No significant difference was found in the 2 constant speed-related problems 1 & 5. In total, the students’ mean post-test score in all the 5 problems was significantly higher than the pre-test one (table 2) indicating a positive learning impact of the activity.

Table 2. Paired Samples Test: students’ mean total scores in pre- and post-test (N = 16).

Mean pre-test score	Mean post test score	t-test	df	Significance (2-tailed)
2.38	3.44	4,259	15	0.001

4 Conclusions

The robotics-based learning activity reported in this paper offers a small-scale study and for that reason we should be cautious to draw any general conclusions from the findings. However, evidence from this robotic activity provided positive indications that it helped the students to improve significantly their graphing abilities related to the phenomenon of motion which in turn is expected to foster better learning of the related physics concepts. Interestingly, this happened in the 3 problems referred to complex motions (forwards and backwards at constant speed, accelerated and then constant speed, accelerated and then decelerated) where students had underachieved before the activity. On the contrary, no significant effect was found in the other 2 problems referred to simple motion events and with the higher pre-test scores.

Furthermore, the reported activity seemed to have triggered the students' interest and turned, to a certain extent, learning into a game thanks to the invention of the competitive “car-racing”. Regarding the attitudinal aspects of the experiement and of the school environment during the robotic activity, it is interesting to quote from the teacher’s report: “the kids in the beginning felt embarrassed staring the robotic kits. Soon their hesitation to be involved changed to enthusiasm. They started examining the content of the package. After having designed a vehicle by paper and pencil, they started the creation of their robotic car. I didn't provide any template. I let the kids to create something according to their imagination and experiementations… it's noteworthy the fact that in some cases kids did not want to stop working and leave the class during the breaks and certainly the phenomenon of the very active participation of students who had not shown any interest in the subject before when they had been taught in the traditional lecture-based way".

References

1. McDermott, L., Rosenquist, M., & van Zee, E:. Student difficulties in connecting graphs and physics: Examples from kinematics. American Journal of Physics, 55(6), 503–513 (1987).
2. Berg, C. & Phillips, D.G.: An investigation of the relationship between logical thinking structures and the ability to construct and interpret graphs. Journal of Research in Science Teaching, 31(4), 323-344 (1994).
3. McDermott, L.: Research on conceptual understanding in mechanics. Physics Today, 57, 24–32 (1984).
4. Trowbridge D.E. & McDermott L.C.:, Investigation of student understanding of the concept of velocity in one dimension, *American Journal of Physics* 48(12), 1020-28 (1980).
5. Ploetzner, R., Lippitsch, S., Galmbacher, M., Heuer, D. Scherrer S: Students' difficulties in learning from dynamic visualizations and how they may be overcome. Computers in Human Behavior 25, 56–65 (2009).
6. Beichner, R: The impact of video motion analysis on kinematics graph interpretation skills. American Journal of Physics, 64(10), 1272–1277 (1996).
7. Thornton, R. K., & Sokoloff, D. R.: Learning motion concepts using real-time microcomputer-based laboratory tools. American Journal of Physics, 58(9), 858–867 (1990).
8. Svec, M.: Improving graphing interpretation skills and understanding of motion using micro-computer based laboratories. Electronic Journal of Science Education, 3(4) (1999).
9. Snir, J., Smith, C., Grosslight, L.: Conceptually enhanced simulations: A Computer Tool for Science Teaching. In: Perkins, D., Schwartz, J., Maxwell West, M., Stone Wiske, M. Software Goes to School, Oxford University Press, pp.106-124.12 (1995).
10. Teodoro, V. D.: Learning with Computer-Based Exploratory Environments in Science and Mathematics. In: Vosniadou, S.,. De Corte, E., Mandl, H. (Eds.), Technology -Based Learning Environments : Psychological and Educational Foundations, NATO ASI Series, Serie F: Computer and Systems Sciences, Vol. 137, pp.179-186. Springer-Verlag(1994).
11. Trowbridge, D.E.: Graphs and Tracks, Physics Academic Software Publishing Organization (1996)
12. Wolfgang, C., Belloni, M.: Graphs and Tracks Revisited. Physics Teacher, 51, 4, 240-241 (2013).
13. Mitnik,, R., Nussbaum, M., Soto, A.: Mobile robotic supported collaborative learning (MRSCL). Lecture Notes in Artificial Intelligence, 3315, 912–921. (2004).
14. Mitnik, R., Recabarren, M., Nussbaum, M., Soto, A.: Collaborative robotic instruction: A graph teaching experience. Computers & Education 53, 330–342 (2009).
15. Detsikas, N., Alimisis, D. :Status and Trends in Educational Robotics Worldwide with Special Consideration of Educational Experiences from Greek Schools. In: Proceedings of the International Conference on Informatics in Schools: Situation, Evolution and Perspectives (ISSEP 2011), Comenius University, Bratislava (2011).

16. Alimisis, D.: Robotics in Education & Education in Robotics: Shifting Focus from Technology to Pedagogy. In: Obdrzálek, D. (ed.) Proceedings of the 3rd International Conference on Robotics in Education, Charles University in Prague, pp. 7-14 (2012).
17. Papert, S., Harel, I.: Constructionism. NY: Ablex Publishing Corporation (1991).
18. Eguchi, A.: What is educational robotics? Theories behind it and practical implementation. In: Gibson, D., Dodge, B. (eds.), Proceedings of Society for Information Technology & Teacher Education International Conference 2010 , Chesapeake, VA: AACE., pp. 4006-4014 (2010).
19. Alimisis, D.: Computer-based modeling as learning tool in kinematics. In: Proceedings of the 6th International Conference on Technology in Mathematics Teaching, University of Thessaly, pp. 191-195 (2003).
20. Berg, C. A., Smith, P.: Assessing Students' Abilities to Construct and Interpret Line Graphs: Disparities between Multiple-Choice and Free-Response Instruments, Science Education 78(6), 527-554 (1994).