Understanding kinematics graphs using MBL tools, simulations and graph samples in an interactive engagement context in a Ghanaian university

Victor Antwi¹, Elwin Savelsbergh² and Harrie Eijkelhof²

¹Department of Physics Education, University of Education, Winneba, Ghana
²Freudenthal Institute for Science and Mathematics Education, Utrecht University, the Netherlands

Abstract. Many students have problems when it comes to describing the shapes of displacement, velocity and acceleration-time graphs (x, v, a-t graphs), conversion of graphs from one form into another, and calculating and getting the meaning of slopes and areas under kinematics graphs. They often describe shapes of graphs as pictures and give interpretation without taking into cognizance of the type of graph being considered. In this study, 37 first year university physics students (Group One: 17 students and Group Two: 20 students) at the University of Education in Winneba (Ghana) in two consecutive years, were introduced to the use of microcomputer based laboratory (MBL) tools; simulations and graph samples to practice and describe the shapes of kinematics graphs; conversion of graphs from one form to the other; calculation of slopes and areas under kinematics graphs, and their meanings, all in an interactive engagement teaching. Students were made to answer the “Test of Understanding Graphs in Kinematics” (TUG-K) before and after the introduction of the use of MBL tools, simulations and graph samples. Students’ scores were compiled and converted to mean proportion scores and average normalized gain (g), under the four concepts “Area under the graph (meaning and calculation); Slope (meaning and calculation); Graph description; and Graph transformation”. The results indicate that the first year university students in the two groups all did better in describing the shapes of kinematics graphs, transforming kinematics graphs, calculating and getting the meaning of slopes and areas under kinematics graphs when they were tested with the same instrument after instruction in kinematics. This goes to show that MBL tools, simulations and graph samples when used in an interactive engagement manner can improve the teaching and learning of kinematics graphs in physics.

1. Introduction

Do you know that some students did not believe that graphs were representation of various kinds of quantitative information and relationships, such that their own movement (walking) could be plotted as graphs? To such students they see graphs as foreign materials, which have no link with any real life activity, used as teaching materials for students to work with. In teaching graphs and during most kinematics physics experiments in Ghanaian university contexts, students are mostly made to plot x-t, v-t or a-t graphs. Teachers usually extend their teaching by asking students to find the gradients of such graphs plotted and perhaps extrapolate or interpolate the graphs to find some other values. These teaching techniques of graphs have made it difficult for students when it comes to describing the shapes of kinematics graphs, conversion of kinematics graphs, getting the meaning and calculating slopes and areas under kinematics graphs, as they are not used to practicing these approaches in class-
rooms. They therefore misinterpret, especially in describing the shapes of graphs, find it difficult to change graphs from one form to another, give different interpretations to slopes and areas under graphs, and find it difficult to calculate the slopes and areas appropriately. In this study, how to use MBL tools and simulations to help students describe and transform kinematics (x, v, a-t) graphs, and how to use specific examples of kinematics graphs to get the meaning and calculate for slopes and areas under graphs, all in an interactive engagement teaching, will be considered. Results of the Ghanaian university students will be converted into mean proportion scores and compared to see how the use of MBL tools, simulations and graph samples in an interactive engagement teaching will improve on their knowledge in kinematics graphs.

2. Results from earlier studies
Graphical representations are important in students’ physics education, especially during physics practical sessions, yet most students have limited understanding of graphs (Blume & Heckman 2000, Swafford & Brown 1989). Numerous studies have shown that students usually find it difficult to convey information with graphs and extract information from graphs (Swatston & Taylor 1994, Wainer 1992).

Students commonly misinterpret graphs as GAP (graph-as-picture), in which they expect the graph to be a picture of the phenomenon described (Beichner 1994, Bollen et al. 2016). Students interpret a graph of displacement versus time as if it were a road map, with the horizontal axis representing one direction of the motion rather than representing the passage of time. In problems dealing with balls rolling in tracks or people riding bicycles over hills, students using GAP will often draw velocity-time graphs resembling the shapes of the tracks or hills, rather than showing the velocity of the ball or bicycle (Murphy 1999). McDermott, Rosenquist and van Zee (1987) found that, even in the simple case of a straight line graph, the physics students in their study confused distance represented by the height of the graph with velocity represented by the slope of the graph in a position-time graph. The situation becomes more complicated when the graphs are curved, making the confusion of slope and height more common. According to Beichner (1994), other common difficulties students have when working with graphs are variable confusion, forming graphs from kinematics equations and graph transformation.

Though some students can calculate slopes, especially straight line graphs which start from the origin, others find it difficult when it does not pass through the origin of the graph. Most students cannot understand what the slope of a line graph connotes (Planinic et al. 2012). For example, students find it difficult to appreciate the fact that the slope of the velocity-time graph connotes acceleration of the object the graph is about. Also, students cannot tell which of two slopes is steeper (Beichner 1994, McDermott et al. 1987).

Similarly, a few students can calculate areas under kinematics graphs and could explain what these areas refer to. For instance, majority of students could not infer that the area under acceleration-time graph refers to the change in velocity of the particular object the graph is about (McDermott et al. 1987, Donnelly & Welford 1989, Eraslan 2008).

3. What do you intend to achieve?
The ability to comfortably work with graphs is a basic skill of the scientist. For example, graph construction, interpretation and transformation are very important and forms integral part of experimentation, which is the heart of science (Chambers et al. 1983, McKenzie & Padilla 1986). Graphs can provide a structured overview of the entire problem situation while still allowing details to be resolved. It has been found out that technology such as the use of microcomputer based laboratory (MBL) tools and simulations is promising for increasing students understanding and transformation of graphs (Mokros & Tinker 1987, Thornton & Sokoloff 1990). This will help students to engage in substantial reasoning to develop coherent understanding of graphs rather than fragmented ideas, which will not set students on the path towards learning. For example, allowing students to interact with motion sensors interfaced with computers to describe their motions could help students to make meaning of the description of their motion in relation to the graph plotted.
In University of Education, Winneba (UEW), the use of MBL tools in teaching is quite recent. The type of MBL tool used is called “Coach 6”. It is a tool which is distributed by the CMA Science in Amsterdam for the active integration of computers in Science and Technology Education, with the view that this learning tool gives the science learner power to explore, measure and learn from the physical world (Kedzierska & Dorenbos 2007). It could also be used to plot graphs easily and quickly on the computer by physical movements of objects, transform kinematics graphs from one form into another (from position-time graphs to velocity-time graphs to acceleration-time graphs) and determine slopes of kinematics graphs.

In this study, we will investigate the effect of MBL tools, simulations and the use of already plotted graphs in the context of interactive engagement teaching to improve students’ understanding of kinematics graphs in a group of first year physics students in a Ghanaian university.

The research question is:
“Could MBL tools, simulations and graphs samples used in interactive engagement teaching lead to students’ conceptual understanding of kinematics graphs?”

4. What are the characteristics of an effective teaching approach in kinematics graphs?
After studying the literature the following sequence of activities were used in the teaching of kinematics graphs: concept quiz, conceptual reasoning questions, interactive teaching, reflection, application and problem solving questions. The purpose of using these activities has been summarized in Fig. 1:

5. Research setting
The research was carried out in the Department of Science Education, University of Education, Winneba (UEW). Participants in the study were first year physics students for two consecutive academic years of their first semester mechanics course. Thirty-seven (37) students were involved in the two academic years: 17 students in Group One and 20 students in Group Two. Understanding kinematics graphs is part of first year mechanics curriculum in UEW. Two out of the 11th-week lessons on mechanics were used to teach kinematics graphs. This consisted of six hours of teaching and four hours of problem solving session. The lecture room was equipped with computers, white board and a screen which allowed for the usage of beamers/projectors. The course was taught by one of the researchers. The research instrument used to gather data was the Test of Understanding Graphs in Kinematics (TUG-K) (Beichner 1994).

6. Method
Students were made to answer (pre) TUG-K a day before the teaching of graphs. During the day of lesson students were made to answer a concept quiz based on description of position-time graph, trans-
formation of position-time graph to velocity-time graph and calculation of gradients. The question is shown below.

Examine the movement of an ant running back and forth along a line in the graphs below.

i. Give a brief interpretation of the position-time graph using the movement of the ant.
ii. Transform the position-time graph of the ant into a velocity-time graph.
iii. Determine the gradients of the various movements of the ant: t = 0-2 s, 2-3 s, 3-6 s and 6-7 s.

Transcription of how some students described the graph
1. **George:** Em!! The first part the, the ant’s velocity was decreasing, and then it increased. The velocity then became constant and then decreased again.
2. [...]  
3. **Peter:** The ant descended, climbed up till it got to a flat surface. It therefore moved for a while and descended again.

After a short discussion of the questions, students were made to answer a question on graph to activate their prior misconception on seeing a graph as picture (GAP). They were made to discuss in groups of four and choose the correct graph which best describes the question (conceptual reasoning question).

Little Johnny stands at the bottom of a small hill and kicks a ball. The ball rolls up the hill and then rolls back to Johnny. Which one of the following velocity-time graphs (A, B, C, or D) most accurately portrays the motion of the ball as it rolls up the hill and comes down?

Transcription of students’ explanations to the choice of their answer revealed that they see graphs as pictures (GAP)
4. **Class (responded):** “A”.
5. **Teacher:** Anybody with different answer?  
6. **Students:** (responded) no sir.
7. **Teacher:** You all chose “A”. Why “A”?
8. **Francis:** Sir, because the ball rolled northwards, then it returned back, which means that, it moves in opposite direction, it will be in southwards direction.
9. [...]  
10. **Tony:** Sir A. Even the graph shows, because the 0 point, the velocity is 0. From the initial to a certain point or a certain height, northwards, then it came back...
The next activity was the interactive teaching, where students in groups of four were made to predict and practice with the MBL and motion sensors to plot graphs of their own movements (straight line graphs). This is shown below:

By the use of motion sensors/detectors and coach students are to observe displacement-time graphs, velocity-time graphs and acceleration-time graphs of the motions below by their movement:
- standing still; students analyze and describe the displacement-time graphs, transform it to velocity-time graphs and acceleration-time graphs of the motion by comparing the shapes of graphs.
- moving at constant speed in a specific direction; students analyze and describe the displacement-time graphs, transform it to velocity-time graphs and acceleration-time graphs of the motion by comparing the shapes of graphs.
- moving away and coming back at constant speed; students analyze and explain the shapes of the displacement-time graphs, transform it to velocity-time graphs and acceleration-time graphs of the motion by comparing the shapes of graphs.
- moving away and coming back with different speed; students analyze and explain the displacement-time graphs, transform it to velocity-time graphs and acceleration-time graphs of the motion by comparing the shapes of graphs.
- moving away, stopping and coming back; students analyze and explain the displacement-time graphs, transform it to velocity-time graphs and acceleration-time graphs of the motion by comparing the shapes of graphs.
- students were made to walk some already plotted x-t and v-t graphs.

By the use of simulations, students predicted and practiced curved x-t graphs and their transformations to v-t and a-t graphs. For example
- students were made to study different dot diagrams of x-t motions with a changing velocity (curved graphs) and their transformations to v-t and a-t graphs. Thus positive and negative changing velocities (slow to fast and fast to slow) were considered. http://www.physicsclassroom.com/
- They were also made to enter different values for initial position (m), initial velocity (m/s), acceleration (m/s²) and time (s). Students were made to study the shape of the position time graph and transform the shapes to v-t and a-t graphs. http://www.physicsclassroom.com/

Students were made to calculate for the slopes and areas of already plotted graphs. Thus
- students were made to practice and determine the value of slopes of a straight line graphs in x-t and v-t graphs (graphs starting from origin and graphs not starting from origin). They were to determine what they were finding (velocity, acceleration).

- students were made to practice and determine the areas under the straight line graphs of velocity-time graphs. They were to determine what they were finding (total distance/displacement).
After allowing students to interact with MBL tools and simulations, they were made to reflect on their initial answers to the conceptual reasoning questions to see if they could improve on their answers (Reflection). All the students opted for “D” as the graph that accurately portrays the motion of the ball as it rolls up the hill and comes down. These were followed by application and problem solving where students could apply, transfer or generalize ideas relating to real world context. Some examples are given.

1. (a) Describe the following graphs.
   (b) Convert graphs 1, 4, 9, 10 & 11 into velocity-time and acceleration-time graphs.

2. Give the meaning of the slope and area under the following graphs:

| Graph                        | Slope                        | Area under the graph |
|------------------------------|------------------------------|----------------------|
| position versus time         | ………………………     | ……………………… |
| velocity versus time         | ………………………     | ……………………… |
| acceleration versus time     | ………………………     | ……………………… |

3. The following graphs were plotted by the movement of the ant shown in the diagram. (i) From the shaded portions of the graphs determine the ant’s displacement.
   (ii) Calculate the gradients of the 1st graph from t = 0-2 s, 2-3 s, 3-5 s and 5-7 s.
Students were made to answer Post TUG-K questions the day after the close of the lesson. The mean proportion scores of students’ Pre TUG-K and Post TUG-K were used to calculate the Hake gain for each Group. The Hake gain values were compared for the Two Groups to determine their level of conceptual understanding in Kinematics graphs. This would help to see how the Ghanaian university students would be affected with the use of MBL tools, simulations and the use of already plotted graphs in the context of interactive engagement teaching in understanding of kinematics graphs. TUG-K is a multiple-choice standardized test, which consists of 21 questions with students common misconceptions as distracters. It is designed to assess students’ kinematics graphing abilities. Students used 30 minutes in answering the questions in each session, due to some quantitative problems involved in calculating slopes and areas under graphs. TUG-K instrument was grouped into four main concepts under graphs and students mean proportion pre and post scores were calculated under these concepts: (i) Area under graph (ii) Slopes (iii) Graph description (iv) Graph transformations.

7. Results
To answer the research question, students were made to answer pre and post TUG-K questions. The mean proportion scores were used to calculate the Hake gain of students and presented in table 1. Students’ mean proportion scores were calculated under the mentioned concepts and presented in tables 2, 3, 4 and 5.

Table 1. Mean proportion correct scores of Pre TUG-K, Post TUG-K, and Gain

| Group            | N  | Pre (SD) | Post (SD) | Hake Gain (SD) |
|------------------|----|----------|-----------|----------------|
| Group One        | 17 | 0.27(0.05)| 0.69(0.07)| 0.58(0.09)     |
| Group Two        | 20 | 0.27(0.06)| 0.71(0.07)| 0.60(0.10)     |

Students’ mean proportion scores in pre TUG-K was lower as compared with their post TUG-K. This was an indication that students did not have enough understanding of kinematics graphs before the beginning of the lesson. However, there was a considerable improvement in the mean proportion scores of post TUG-K. Also, the average normalized gain, \( g \), was about 0.6, which falls within Hake’s medium-g courses, \( 0.7 \geq [(g)] \geq 0.3 \), which is a typical range for average effectiveness of courses in promoting conceptual understanding (Hake 1998). Hake developed his score for FCI but not for TUG-K, and along the same line we extended his way of calculation for TUG-K gain scores. The mean proportion scores of the two Groups were comparable.

Table 2. Comparing students’ mean proportion correct scores in Pre and Post TUG-K- in area under graph (meaning and calculation)

| Concept (meaning & calculation) | TUG-K Que. No. | Group            | N    | Pre (SD) | Post (SD) |
|---------------------------------|----------------|------------------|------|----------|-----------|
| Area under graph                | 1, 4, 10, 16, 18 & 20 | Group One        | 17   | 0.28(0.02)| 0.72(0.14)|
|                                 |                | Group Two        | 20   | 0.32(0.02)| 0.74(0.08)|

The performance of students in Pre TUG-K of both year groups was relatively lower as compared with that of their Post TUG-K. This indicates students’ lack of understanding in areas under kinematics graphs at the beginning of the lesson. However, relatively higher mean scores of Post TUG-K show that concept of areas under kinematics graphs were highly appreciated by students after the interactive teaching.
Table 3. Comparing students’ mean proportion correct scores in Pre and Post TUG-K- in slope (meaning and calculation)

| Concept                      | TUG-K Que. No. | Group       | N  | Pre (SD)  | Post (SD) |
|------------------------------|----------------|-------------|----|-----------|-----------|
| Slopes (meaning & cal.)      | 2, 5, 6, 7 & 17| Group One   | 17 | 0.46(0.03)| 0.63(0.13)|
|                              |                | Group Two   | 20 | 0.49(0.02)| 0.68(0.07)|

Students’ Pre TUG-K scores in both year groups were relatively lower; they were not as low as the other concepts. This is not surprising as most of the graph works that students do, especially in Ghana, are based on plotting graphs with given data, and calculating for the values of the slopes. Also, mathematics items in slopes are less difficult for students to solve (Planinic et al. 2012). However, their post scores were relatively higher, which is an indication that the intervention was helpful in enhancing students’ understanding.

Table 4. Comparing students’ mean proportion correct scores in Pre and Post TUG-K- in Graph description

| Concept                        | TUG-K Que. No. | Group       | N  | Pre (SD)  | Post (SD) |
|--------------------------------|----------------|-------------|----|-----------|-----------|
| Graph description              | 3, 8, 9, 12, 19 & 21| Group One   | 17 | 0.22(0.02)| 0.68(0.12)|
|                                |                | Group Two   | 20 | 0.20(0.02)| 0.68(0.07)|

Students’ Pre TUG-K scores in description of graphs were relatively lower. This might be due to the way they saw graphs as pictures before the beginning of the lesson. There was a significant improvement in their scores in Post TUG-K after the lesson. This shows that the intervention in describing graphs might have had a positive effect on students’ graph description (Thornton & Sokoloff 1990).

Table 5. Comparing students’ mean proportion correct scores in Pre and Post TUG-K- in graph transformation

| Concept                      | TUG-K Que. No. | Group       | N  | Pre (SD)  | Post (SD) |
|------------------------------|----------------|-------------|----|-----------|-----------|
| Graph transformation         | 11, 12, 13, 14, 15 & 19 | Group One   | 17 | 0.14(0.03)| 0.70(0.05)|
|                              |                | Group Two   | 20 | 0.18(0.03)| 0.70(0.05)|

Students’ Pre TUG-K mean proportion scores in graphs transformation were relatively lower. This is because graph transformation is rarely taught in Ghanaian schools. However, their relatively higher score in Post TUG-K might be attributed to the interventions in graph transformation during the lesson.

8. Conclusions
We have described how MBL tools, simulations and graph samples have systematically been structured into a sequence of activities in the context of interactive engagement teaching of kinematics graphs in the physics curriculum of a Ghanaian university. We noted more students’ participation in class, high interactions among the students and also between the students and the computer. Students had high and almost equal gains in both year groups, which seem to confirm that the use of interactive engagement (IE) methods through MBL tools, simulations and graph samples in the classroom can increase graph teaching effectiveness well beyond that obtained in traditional practice (Hake 1998), though we cannot exactly know what really was most effective. Furthermore, students showed good conceptual gains in understanding of kinematics graphs, especially in getting the meaning and calculating for the area under graphs, knowing the meaning of slopes of graphs and also calculating for their values, description of graphs and graphs transformations. The difference of Post-TUG-K and Pre
TUG-K mean scores in both year groups was an indication that students’ understanding in graphs have improved. Thus students had better understanding of kinematics graphs after the instructions in kinematics graphs with the use of MBL tools, simulations and graph samples.

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