USING REAL -TIME GRAPHS TO ENHANCE UNDERSTANDING OF KINEMATICS GRAPHS: MOTIONS DETECTORS IN THE PHYSICS CLASSROOM

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ABSTRACT
The activities and the case study were inspired by publications uncovering a consistent set of student difficulties with graphs of position, velocity and acceleration versus time. Research indicates that the use of a Motion Detector is effective, particularly in the area of graphical interpretation. In an early study Thornton and Sokoloff found that students using real-time graphs improved their kinematics graphing skills and their understanding of the qualitative aspects of motion they observed, compared to students using delay-time graphs.
The author is investigating the pedagogical potential of using graphing calculators in combination with a Motion Detector enabling students to extract most of the rich information content of kinematics graphs. Experiences have been made in grade 6, 9 and 10 (with 11, 14 and 15-year old students in an Austrian school) are reported. Didactical approaches and examples for methodologically embedded classroom activities are presented.
The use of technology seems to effectively enhance students' learning. Students were actively engaged in learning as they made predictions, took measurements, analyzed their data and made decisions about presenting their work. Beside these motivational benefits the technology-enriched learning environments had positive impacts on the learning outcomes, which were assessed with TUG-K, a test of Understanding Graphs in Kinematics.

KEYWORDS
Kinematics Graphs, Motion Detector, TI technology, TUG-K (Test of Understanding Graphs in Kinematics)

INTRODUCTION

Although students are introduced to the topic of graphs and motion early in their study of physics, educational research shows that most cannot apply the concepts of position, velocity and acceleration to real motion (McDermott, 1998). Traditional physics courses even at the secondary school level do not make strong connections to the everyday experiences of the students by examining simple understandings and addressing misconceptions. Findings of research have indicated two ways in which students commonly misinterpret graphs, particularly graphs of motion events: Students expect the graph to be a picture of the phenomenon described and interpret a graph of distance vs. time as it were a road map, with the horizontal axis representing one direction of the motion rather than representing the passage of time. The second common misconception seems to be confusion between the slope and height of lines on the graph. It appears that there is a strong connection or interaction between students' conceptual difficulties in kinematics and their difficulties in interpreting graphs that are used to represent kinematics phenomena and concepts (McDermott et al., 1987).

Researchers claim that microcomputer-based laboratory (MBL) activities are effective in improving students' understanding of graphs of physical events (Thornton, 1987). Thornton & Sokoloff (1990) used MBL instruction with motion sensors to teach kinematics to 1500 students in several college and university physics courses. They write: "There is a strong evidence for significantly improved learning and retention by students who used the MBL materials, compared to those taught in lecture" (Thornton & Sokoloff, 1990), p. 862).

Although technological innovations have the capability to significantly change how scientific investigations are done and greatly enhance the teaching and learning of science, its use is no more effective than any other resource or innovation when research-based effective teaching practices are not followed (Bryan, 2006). For the integration of technology into science classrooms and for the preparation of science teachers, the following standards have been proposed by leading science education organizations (Flick & Bell, 2000):

- Technology should be introduced in the context of science content.
- Technology should make scientific views more accessible.
- Technology should address worthwhile science with appropriate pedagogy.
- Technology instruction in science should take advantage of the unique features of technology.

According to Mottmann (1999), two of the more important reasons for introducing technology and other instructional innovations into physics education are “(1) to improve students’ physics ability and (2) to improve students’ negative reactions towards physics” (p.75).

From the constructivist view of how scientific knowledge is acquired the student is not viewed as a passive recipient of knowledge but rather as an actor in its creation significantly affected by the knowledge the student already has. For developing the conceptual understanding and reasoning skills necessary to teach science as a process of inquiry, McDermott developed materials through an iterative process of research, curriculum development and instruction (McDermott, 1996). McDermott’s conceptual approach to teaching kinematics engages students in structured laboratory-based activities and helps them develop a qualitative understanding of instantaneous velocity, constant acceleration and the distinction between these two concepts. They are supported to develop the ability to translate back and forth between actual motions and their graphical representations.

Uncovering students’ problems with interpreting kinematics graphs can be very helpful before, during and after instruction. The TUG-K (Test of Understanding Graphs in Kinematics) developed by Beichner (1994) consists of 21 multiple choice questions measuring only kinematics graph interpretation skills. Common errors were included as distractors by asking open-ended questions to a group of students and then using the most frequently appearing mistakes as distractors for the multiple-choice version of the test.

THREE EXAMPLES USING MOTION SENSORS

Whereas earlier studies (McDermott, Thornton & Sokoloff, Beichner) concentrate on college and university students the main focus of this study is on secondary school students. Studying how motion in one direction can be described in terms of the concepts of position, displacement, velocity and acceleration, three didactical approaches at different school levels and different settings are described. The motion sensor with substantially the same hardware and software was used with different age-groups – 6^{th} grade secondary school children to 10^{th} grade high school students.

Beginning from introducing students of the 6^{th} grade to graphical representations of real motion with constant speed in the first example, the students of the 9^{th} grade in the second example were considered to study the motion of objects that were speeding up and slowing down. In the third example aims, research questions, methods and results of a case study with two classes [10^{th} grade] are reported.

(1) Introducing position vs. time graphs in the 6^{th} grade

In the 6th grade (11-year old students in an Austrian secondary school) 29 students (16 boys and 13 girls) were introduced to the use of motion sensors used along with graphing calculators by teacher demonstration only due to resource and time constraints. Therefore the teacher carried out interactive demonstration tasks with students together using a whiteboard in a single one 50-minute period, introducing them to the graphical representation of their own body motion through position vs. time graphs.

As the students moved their bodies, they and their classmates were able to watch the graph being drawn simultaneously on the screen. Motion sensors used along with graphing devices allow graphs to be viewed while the data is being collected. As a student walks towards or away from a motion sensor, the position versus time graph of his/her walking will be immediately graphed. This means that as the student moves, his/her body motions will be graphed before his/her and the classmates' eyes. From such graphical representation it is possible to determine in what direction an object is going, how fast it is moving, how far it travelled and whether it is speeding up or slowing down. Immediately afterwards the plotted graph can be traced in order to combine real motion and graphical representation and make students familiar with visualization of linear motion.

The application EASYDATA of the TI84 Plus supports the activity "Distance vs. Time Graphing" by generating random target distance graphs consisting of three linear parts. The students have to study the graphs and write down how they would walk to produce the target graph shown on the screen. By making this graph visible through presentation at the whiteboard to the whole class, each student can think about the graph on his/her own. Then one student tests his/her prediction, chooses a starting position and then walks in the considered way to match the target graph on the calculator screen. When the student is not successful the first time the process can be repeated until the motion closely matches the graph on the screen.

For homework students had to write a short essay about what they have learned including at least one position vs. time graph.

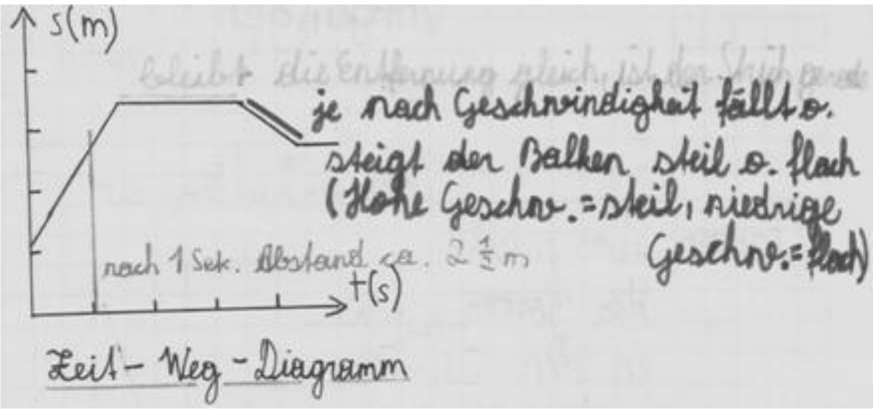

Figure 1. Position vs. Time Graph (focusing on the term velocity)

As some of the information in Figure 1 indicates, there is evidence to suggest that students may have probably developed their own intuition or definition of velocity even as the term "velocity" was not used by the teacher during the whole lesson. As Paul writes: "If the distance stays the same the line is horizontal. Depending on velocity the line is ascending or descending; for low velocity less and for higher velocity more." (see Figure 1) it would appear that he has constructed his own definition of velocity. Some of the other students' essays reveal to some extent that the "playing-character" is rather dominant; the students view the exercise "graph-matching" like playing a game with the graphing calculator. For example, Amanda writes: "In this game the graphing calculator gave me a picture and I should match it as well as I could."

However the students had not been previously introduced to motion and graphing, the use of motion sensors seems to be an effective means of teaching students at grade 6 to understand motion and graphing. Even ten months later, more than 70% of the students were able to make position vs. time graphs for an object which for example is at rest three meters from the motion detector, then moves towards the motion detector with a constant speed of 0.5 m/s for 3 seconds, then turns round and moves with a constant speed of 1 m/s for 2 seconds away from the motion detector.

(2) Actively participating in scientific investigations in laboratory work

In the 9th grade (14-year old students in an Austrian high school) students have 2 physics units (each lasting 50 minutes) each week. In that particular school, the two units are divided into one 50 minutes lesson and one 50-minutes-physics laboratory unit each week. For obvious reasons, these two paths need to be interlinked. The main topic in the 9th grade physics is mechanics and the physics teacher of the class decided to use motions sensors in combination with graphing calculators in the laboratory exercises. 19 students (15 boys and 4 girls) took part in the study. Graphing calculators are well known to the students as they are used in mathematics lessons and therefore every student owns a calculator and is familiar with the technological use of it.

The motion sensor in combination with the software and the graphing calculator gives the user a means of measuring physical quantities and displaying them graphically at the moment of measurement. The students in this class were able to transform the data (e.g. by changing the graph scales) and save the data for later analysis. Accompanying materials guided students through initial investigations and on to their own investigations encouraging an inquiry-based approach to science learning.
Starting out from using the motion sensors for investigation for the motion of their own bodies and graph-match-exercises students were guided to explore different motion examples for helping them to overcome some conceptual difficulties in kinematics. Based on the review of literature, a course over 12 lessons laboratory work has been designed to support conceptual change in learning kinematics concepts by extending the range of students' investigations. With the help of motion sensors, students need not consider only specialized cases such as uniform motion of nearly frictionless objects. From that course two examples are reported.

a) Beginning with cases for motion with constant speed, students were asked to produce the most uniform, steady motion they can, using balls and tracks. Then they had to check (with and without the motion sensor) whether the motion was uniform and afterwards they had to explain why they believed that their method was a good test for a uniform motion. They also had to provide quantitative evidence that the motion was uniform and finally write down an operational definition of uniform motion. These investigations lead to the quantity velocity used in describing uniform motion to be the displacement that occurs in one unit of time. Graphical representations of real motions are also useful to focus on the distinction of velocity and speed (velocity includes the direction of motion as well as the number of meters travelled each second whereas speed does not indicate direction).

b) The next experiment illustrates the value of rapid collection and display of data in assisting thinking about the phenomenon under investigation. The students shall explore motion on a sloping surface and conduct an experiment allowing both acceleration and deceleration to be investigated by "data-logging" the output from a motion sensor. They prop up a runway at one end to create an inclined plane. Next they clamp a wooden block to the lower end to make a solid barrier. A dynamics trolley with a spring plunger pointing forwards is allowed to roll down the runway. The motion sensor is placed at the top of the runway and connected to a graphing calculator. After configuring the data-logging software to measure the distance of the trolley from the sensor, the data collection is started. Data is collected within a few seconds and the graph is presented simultaneously. This helps students to make connections between features on the graph and the actual motion of the trolley. It is a useful teaching strategy to ask students to make a prediction about the appearance shape of the graph, before the program actually plots the result. Comparing the result with the prediction can promote discussion. For analysis the students are asked to observe the graph as a succession of half loops and identify specific points and parts on the graph. There are several additional interesting features of the graph which invite explanation, e.g. the asymmetry of each half-loop. Next the students shall study the velocity of the trolley using the data from the position vs. time graph and plotting the rate of change of distance against time. They learn that both positive and negative velocities change linearly, indicating uniform acceleration and deceleration with slightly differences.

Students' activities during courses have been observed and documented. Students were asked to describe their learning experiences in interviews and essays. At the end of the curriculum, students were asked how useful the lab exercises were. Several methods have been combined to gain insight into activities and into the individual student's perspective:

- Interactive observation, documented in a research diary
- Technical documentation
- Questionnaires, essays and exercise sheets

About 40 % of the students reported that the activities challenged them and that they were encouraged to critical thinking. It appears that the students are fairly stimulated to acquire information by self regulated learning and following own investigations as the drudgery of data collection and manipulation can be reduced through measuring phenomena over time-scales that can be much shorter than with the typically used methodology. The majority of the students also appreciate the immediate presentation of the data in a form that can be thought about and understood. As interactive observation suggests the technology based activities lead to discussions among lab partners that result in learning. Especially less gifted and not highly engaged students appreciated the values of the electronic equipment enabling them to focus their attention on the experiment and on discussion rather than on complicated calculations.

(3) Students' interpretation of kinematics graphs by incorporating a motion sensor
The aim of the case study was to incorporate activities with the motion sensor in conjunction with graphing calculators in a 10th grade class in an Austrian high school and to evaluate the progress of the kinematics graphing skills. The students had at this time neither experiences with sensors nor calculators and there were no extra laboratory lessons compared to the example described in paragraph (2). The use of sensors and calculators was embedded in traditional classroom teaching where students worked in groups using sensors and calculators. A pre-test – post-test – follow up-test design was used with a treatment group and a control group. Further details of the study are described below.

RESEARCH QUESTIONS

Specifically, the following two research questions were raised:
(1) Do the learning outcomes differ between the two groups?
(2) Do the learning outcomes of both groups depend on the pre-existing knowledge assessed by the pre-test?

METHODS AND SAMPLES

The study was performed over the course of three months, when kinematics was the subject of the physics course in two 10th grade classes of an Austrian high school where the sample for this study was chosen. A class (class 6W) of 23 students took part in the study as a treatment group, a parallel class (class 6G) of 24 students was used as a control group. At grade ten, students attend two physics lectures per week, each lasting 50 minutes. The treatment group (class 6W) spent eight lectures during these three months in the physics lab with motion sensors. The students were familiarized with the motion sensors and the graphing calculators and were helped to construct their understanding through inquiry-based investigations. The instructions had well defined learning goals and were designed to guide, but not excessively constrain, the students' exploration of the lab examples.

Students of both groups were taught the same content but the students in the control group did not use any electronic equipment like motion sensors and graphing calculators. In the control group only traditional teaching methods were used; the students also worked on graphs and motion but only in a fairly traditional way drawing and interpreting diagrams but definitely without any graphing calculators and motion sensors.

To examine the pre-existing knowledge in the field of understanding graphs in kinematics, a pre-test containing 6 two-tiered questions, where the students could gain a maximum of 30 points was administered before the start of the intervention in both classes (see Figure 2 and Table 1).

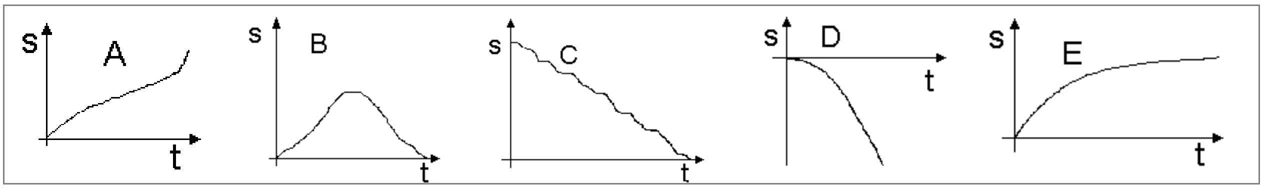

Figure 2. Question on the Kinematics – Pretest

An example for a question on the pre-test is Q1: There are five position vs. time graphs shown in Figure 2. Table 1 continues five textual motion descriptions. Select the right textual description for each graph and write the number (1 to 5) of the description chosen near to the letters (A to E). Give an explanation for each of your answers in the table below.

Table 1. Textual motion descriptions on the Kinematics – Pretest

1	A car is travelling through the inner city of Vienna on Saturday Morning.
2	Wendy carries out a 1000-meter run. At the beginning she runs faster then afterwards and at the end of the run she performs a magnificent sprint.
3	An ICE-train decelerates after pulling the emergency brake.
4	A water bomb falls from the third floor of the school building.
5	Mrs. Flynn goes to the bakery and home again.

For the post-test and the follow up-test the TUG-K was used (Beichner, 1994). The post-test was performed close to the end of the course in both classes; the follow-up test was administered 10 weeks after the post-test again in both classes. During these ten weeks, students in both groups were confronted with similar tasks where they should apply their knowledge about graphs.

RESULTS

There was no significant difference between the treatment group and the control group according to their pre-existing knowledge (see Table 2).

Table 2. Oneway ANOVA for the pre-test

	Sum of squares	**df**	**Mean of squares**	**F**	**Significance**
Between groups	.235	1	.235	.021	.885
Within groups	501.978	45	11.155		
Total	502.213	46			

Table 3 gives an overview at the average points on the TUG-K reached at the post-test (SK) and the follow up-test (SE) for both groups. While there was no difference in the pre-test score, the group with access to motion sensors and graphing calculators performed significantly better by 3.35 more points (out of a total of 21) in the follow up-test compared to the control group.

Table 3. Average points gained at the post-test and follow up-test

	Class	SK	SE
6G	Mean	7.00	7.25
	N	24	24
	Standard deviation	3.323	3.274
6W	Mean	9.35	10.57
	N	23	23
	Standard Deviation	4.334	4.121
Total	Mean	8.15	8.87
	N	47	47
	Standard Deviation	3.989	4.036

The box-plot diagrams in Figure 3 indicate that the median for the experimental group (6W) at the follow up-test is more than five points higher than the corresponding median for the control group. Where as the median in the control group decreases a little between post-test (SK) and follow up-test (SE) the median in the treatment group raised by more than two points.

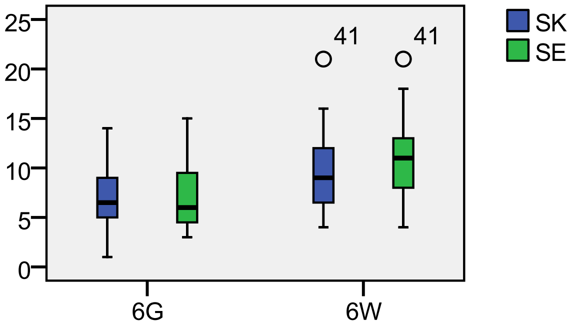

Figure 3. Results for the post- and follow up-test for both groups

Taking a closer look at the scores on the TUG-K demonstrates which items show the largest differences between the two groups (see Figure 4). One of these items is K13. In K13 of the TUG-K, students are asked the following: “Distance versus time graphs are shown in Figure 5. All axes have the same scale. Which object had the highest instantaneous velocity during the interval?” (see Figure 5).

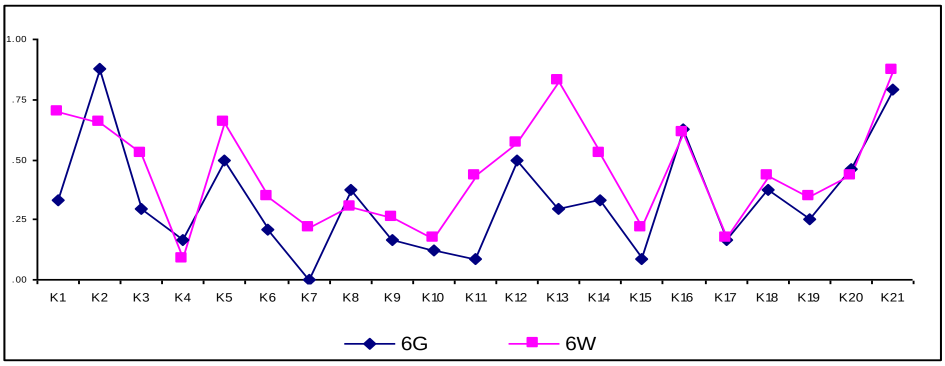

Figure 4. Results for the TUG-K at the post-test for both groups

As Figure 4 demonstrates, only 29% of the students in the control group can answer this question correctly whereas the percentage of correct answers in the treatment group is 83%.

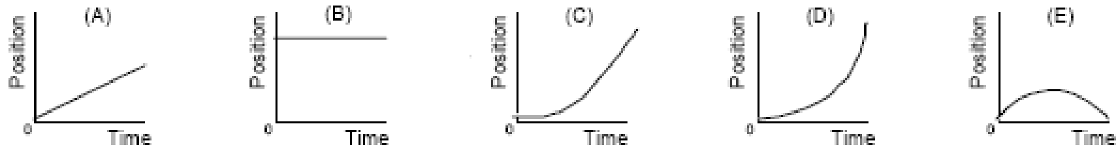

Figure 5. Question K13 of the TUG-K

But there are also items with a small or nearly zero difference (e.g. K10, K16, K17, K20).

We can find also questions were the students of the control group perform better than their colleagues in the treatment group. Most of these questions (e.g. K2, K4) are related to some kind of calculation skills as shown in Figure 6 for the Question K4 where the students were asked the following: “An elevator moves from the basement to the tenth floor of a building. The mass of the elevator is 1000 kg and it moves as shown in the velocity-time as shown in Fig. 6. How far does it move during the first three seconds of motion? (A) 0.75 m, (B) 1.33 m, (C) 4.0 m, (D) 6.0 m, (E) 12.0 m?”

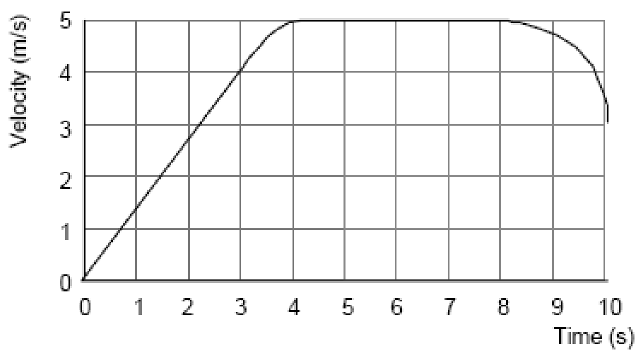

Figure 6. Question K4 of the TUG-K

As the presented data in Table 4 (r-squared = 0. 567) clearly indicate three factors have a high significant impact on the dependent variable SE (TUG-K points at the follow up-test). These independent factors are: SP (points at pre-test), Class (affiliation to the treatment group as dummy variable) and SK (TUG-K points at the post-test). Students who were both in the treatment group and had high scores at the pre- and post-test performed better at the follow up-test than students of the control group with fewer points at the pre- and post-test.

Table 4. Regression analysis for the results at the follow up-test

	Modell	**Sum of squares**	**df**	**Mean of squares**	**F**	**Sig.**
1	Regression	424.467	3	141.489	18.73	.000[a]
	Not standardized residuals	324.767	43	7.553		
	Total	749.234	46			

a. Factors : (Constants), SP, Class, SK

b. Dependent Variable: SE

Table 5 shows that the impact of the pre-existing knowledge SP is not significant.

Table 5. Coefficients for regression analysis related to Table 4

Model		Not standardized coefficients		Standardized coefficients	T	Sig.
		Regression coefficient B	Standard error	Beta		
1	(Constant)	2.120	1.201		1.765	.085
	Class	1.832	.847	.229	2.164	.036
	SK	.626	.119	.619	5.248	.000
	SP	.091	.138	.074	.658	.514

a. Dependent variable: SE

DISCUSSION AND CONCLUSIONS

It is noted, that although there were no differences between the two groups in age, curriculum, number of hours taught, pre-existing knowledge, etc., both groups had different teachers, so that the high significance of the dummy variable "Class" could theoretically also be due to differences in teaching abilities and effort. However, as the control group teacher was carefully selected to minimize a potential teacher bias in the estimation, the significance of the dummy variable is attributed primarily to the access to electronic equipment.

As the results show, motion sensors in combination with graphing calculators can lead not only to enhanced performance in formal tests but also induce a change from passive reception to active learning, "constructing" knowledge rather than abstract memorizing. There are no significant gender differences between boys and girls.

The instruments can be powerful tools that are able to help students within a wide range of ages and abilities learn kinematics. Because of these pedagogical advantages, using sensors in laboratories or classroom teaching can provide a foundation for the restructuring of physics teaching in order to provide effective experiential learning. As the teacher of the treatment group in the case study reported, the interactive simulations generated a high level of students' engagement, exploration and discussion.

The use of graphing calculators in conjunction with motions sensors seems to enhance understanding of kinematics graphs. Taking a closer look at the results, it has to be mentioned that it is necessary to differentiate at least between two types of test-questions: (1) Questions that are related to some kind of calculation skills and (2) questions that are not related to any calculation skills. Although students of the control group have significant fewer points at the whole test, these students perform better than their colleagues of the treatment group for questions of type 1 as they are probably more used to calculations made by hand. Therefore it seems to be necessary to regard the type of competences the students should achieve. If the teacher wants them to do calculations on motions diagrams very well it turns out that it may not be very appropriate to use graphing calculators and motion sensors. If the focus is on understanding kinematics graphs there is some evidence that graphing calculators and motion sensors seem to enhance students' learning.

The information obtained from future studies within this area may determine more details whether "motion-sensor-enriched laboratories" promote students' conceptual change in interpreting graphs and grasping fundamental kinematics concepts within different areas of age. The replication studies are needed to investigate how "motion-sensor-enriched laboratories" and accompanying materials can be designed effectively to support learning and conceptual change. More diverse random samples and long-term studies should be performed to improve significance.

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