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Being Smart About SmartGraphs

Findings From an Experimental Trial in Physical Science Classrooms

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Introduction to SmartGraphs

At all education levels, graphing is important both in science and in mathematics classes, and in recent decades "graphs and other mathematical representations have come to play an increasingly important role in mathematical activities in schools" (Monk, 2003). Yet, in spite of the central role of graphs, students at all ages demonstrate difficulties interpreting graphs (Woolnough, 2000; Zee & McDermott, 1987). In response to a grant proposal on this subject, the National Science Foundation funded the Concord Consortium to design, develop, test, and disseminate SmartGraphs software and activities (http://www.concord.org/smartgraphs) to help students better understand graphs and the concepts represented in graphs.

SmartGraphs software allows authors to create lessons or activities that run in a Web browser, without any special installations or downloads. The software is programmed using HTML5. One exception is that some activities make use of motion sensors connected to the computer, and in those cases an invisible Java applet is used, which requires that Java be installed on the student's computer. Otherwise, SmartGraphs activities do not use Java, Flash or any other plug-in or software besides a modern Web browser. This helps assure that these activities are usable in any school with an Internet connection.

SmartGraphs activities allow students to interact with graphs, for example by clicking on a point in a graph to answer a question. Visualizations (including animations connected to graphs, and colored highlights on graphs), multiple representations of concepts (such as a table linked to a graph), and other instructional approaches are used that have been demonstrated to show promise in mathematics and science education (Rangel & Linn, 2007).

In addition to developing and testing activities for students, the SmartGraphs project is also developing an authoring system. The authoring system allows non-programmers to create and disseminate SmartGraphs activities of their own design.

SmartGraphs is free of charge to users. The software itself is open source, meaning that the computer code is available to anyone. Activities are being released under a Creative Commons license that allows people to use and to share the activities at no cost.

The SmartGraphs Study Focusing on Physical Science

Although a few examples can be found (e.g., Campuzano et al., 2009; Dynarski et al., 2007; Roschelle et al., 2010), large-scale randomized studies of the use of technology in schools are rare. The large-scale study we are conducting for SmartGraphs focuses on learning certain core concepts in science, which is an important subject required for almost all students in the United States. For these reasons, as well as the great national interest in using technology for education (e.g., NSF Task Force on Cyberlearning, 2008; U.S. Dept. of Education, 2010), this study of SmartGraphs may be of wide interest.

SmartGraphs can be used for teaching and learning in a variety of courses and for many different topics. In order to conduct a focused, well-controlled study, we chose to study a single topic in a single course. The study focuses on a unit about the motion of objects, as taught in a typical 8th or 9th grade Physical Science class. In Pennsylvania, where the research was conducted, there were more than 75,000 enrollments in such courses in school year 2006-2007. Because the topic and the course are considered important by many teachers and students, and because graphs (of position vs. time and velocity vs. time) are central to the topic, this focal point was considered to be a sensible one for research about the efficacy of SmartGraphs.

Pennsylvania's Classrooms for the Future program has purchased more than 140,000 laptops for high school classrooms across the state, which was an important reason why Pennsylvania was selected as the location for the research. Class sets of computers are available in almost every high school science classroom in the state.

Five SmartGraphs activities were developed about the motion of objects, each requiring about one class period for students to complete. The first three activities incorporate use of a motion sensor. The activities (which can be accessed via the project's website) are:

1. **Maria's Run**: Shows that the motion of an object can be described by its position, direction of motion, and speed.
2. **Motion Toward and Away**: Explores different ways of describing motion on a graph.
3. **How Fast Am I Moving?** Uses the position of an object at several times to determine the direction and velocity traveled during different time intervals.
4. **Describing Velocity**: Connects the motion of an object to the corresponding position-time and velocity-time graphs to determine the velocity during different intervals.
5. **Was Galileo Right?** Explores the effects of gravity on light and heavy objects during free fall.

Two key research questions guided the study, one focusing on students' learning and the other, a descriptive question, focusing on teachers' opinions about the activities:

1. Do students who use SmartGraphs activities learn more than comparison students studying the same topic from the same textbooks, but who do not use SmartGraphs activities?

2. What do teachers using SmartGraphs physical science activities believe about the software, including its match to important learning goals for the motion unit of study?

Teachers were recruited to participate in the SmartGraphs study through the Pennsylvania Department of Education listserv, as well as by word of mouth. To participate in the study, teachers had to meet the following requirements:

- They must be teaching 8th or 9th grade physical science in the 2011-2012 school year;
- They must anticipate teaching 8th or 9th grade physical science in the 2012-2013 school year, as participation in this study is a two year commitment;
- They must be using one of three designated textbooks (Glencoe, Holt McDougal, or Pearson) in order to ensure similarity of curriculum; and,
- They must have regular and reliable access to computers for all students.

Ultimately, there were 35 teachers qualified to participate in SmartGraphs. The teachers were then assigned to experimental (SmartGraphs) or control (curriculum as usual) groups at random. Teachers in the same school were automatically assigned to the same group. The number of teachers per school was limited to a maximum of two so as not to have one school over-influence the results. For all teachers, at most three sections of physical science were selected for the research. If a teacher had more than three sections, the participating sections were selected at random.

Training took place in August 2011 in both King of Prussia, Pennsylvania and in Pittsburgh. In each location, there were two 2-day training sessions, one for the experimental group and one for the control group. Teachers were not told of their assignment until they arrived at training. During the training, the SmartGraphs (experimental) teachers were introduced to the five SmartGraphs activities, the requirements of the study, and were shown how to use the SmartGraphs portal system. The control teachers were introduced to a number of activities involving temperature sensors that they could use with their classes for physical science topics related to heat and temperature. The heat-related activities were provided instead of the SmartGraphs activities, so control teachers would gain something valuable from the training tied to the use of technology. Teachers in both groups were given three motion sensors to bring back to their classes. By ensuring that all teachers had at least three motion sensors (in addition to any already at the school), we could be sure the research results were due to use of SmartGraphs activities, not to the availability of motion sensors.

There were several other requirements for all participating teachers. They needed to administer an online pre-test to students by September 15, 2011. They also needed to administer the identical post-test to students immediately after completing the motion unit, but before December 23, 2011. All teachers also needed to complete online weekly logs beginning from the first week they taught motion until the week they gave the post-test. (Development of the tests and the logs is described below.) The only additional requirement was for the SmartGraphs teachers to use at least four SmartGraphs activities while they taught the motion unit. Between training in August and the end of December, all SmartGraphs teachers completed their obligations, and thus all of them remain in the study.

Instrument Development

Two instruments were developed for this study: a pre/post test, and a teacher log. Each is described below. Before creating the instruments, a set of 13 learning goals was developed reflecting the use and understanding of graphs as related to the motion unit of a physical science course at the eighth or ninth grade level. The learning goals were developed based on analysis of Pennsylvania's science standards and the physical science textbooks commonly used in the state. Four eighth and ninth grade physical science teachers reviewed these learning goals to confirm that they are, in fact, targets of instruction and that they are grade appropriate. An example of a learning goal used for this project is "Identify constant, positive, negative, and 0 rates of change in position with respect to time, from a position-time graph."

Pre and post-tests

An experienced item writer was hired to write items matching the learning goals. The items were both multiple-choice and open-response. Specifically, the open-response items were developed to use a knowledge-integration scoring rubric. The knowledge integration rubric assesses student ability to "connect scientifically normative and relevant ideas in explaining a scientific phenomenon or justifying their claim in a scientific problem" (Lee & Liu, 2009). Most of the knowledge-integration items included a multiple-choice or short answer part, followed by an explanation of that answer. The item writer developed 60 items. These items were then evaluated by four physical science teachers to confirm that the items matched the content of their courses as well as the learning goals, and that they were grade appropriate. After some items were discarded, remaining items were divided into three tests with some common items and these tests were piloted with 235 8th and 9th grade students. Pilot tests were delivered online via SurveyMonkey. Results were scored and evaluated using descriptive statistics as well as Rasch analysis. Twenty items were selected for the final test. These items address all of the learning goals and have strong psychometric properties.

Weekly logs

Teachers were instructed to complete a log detailing their work during a week of class. They began the logs after the first week they began teaching the motion unit. The last log was completed the week they finished teaching motion (the week they gave students the post-test). Teachers completed a separate log for each section participating in the study. Logs were completed online using SurveyMonkey. All teachers needed to answer questions regarding the amount of time spent on specific content within a typical motion unit. They also reported on their software usage aside from SmartGraphs, especially use of probes or sensors, along with how any software was used in class (as a whole class activity, with small groups, or individually).

The SmartGraphs teachers were also expected to report on their use of the SmartGraphs activities. Specifically, for each activity completed they were asked what class format they used to complete it (whole class, small groups, or individuals), how many sensors were used, the amount of time spent preparing for and conducting the activity, and what resources they used (the teacher's guide or the student assessment, both available via the SmartGraphs portal). Teachers were also asked to rate how well the activity addressed learning goals of their class, whether the integration of graphs was appropriate, whether the material was accessible to their students, and if it helped students to meet the learning goals of the activity. Finally teachers were asked if they would use the activity again.

Data and Findings

Data from the pre and post-tests and the logs were collected to answer both of the research questions.

Teachers' Opinions about the Activities

Eighteen experimental teachers used SmartGraphs activities with students 203 times during the fall of the 2011-2012 school year. Each teacher used the first four activities with his or her physical science classes. The fifth activity was not available until the end of October, by which time many of the experimental teachers had completed the motion unit. As a result, teachers reported using the fifth activity with students only eight times.

In about 87 percent of the cases teachers had students use the activities individually or in small groups. By contrast, in 12 percent of the cases teachers reported presenting the activities to the whole class using a computer projector.

The great majority of teachers agreed or strongly agreed that the SmartGraphs activities addressed important learning goals and helped students meet those goals. Teachers were asked to respond to five questions about the learning goals, as numbered below, marking their opinion about each item on a five-point scale from Strongly Agree to Strongly Disagree. Teachers' responses are shown in Table 1, below.

1. The activity addressed the learning goals of my physical science class.
2. I usually teach the content of this activity.
3. The integration of graphs was appropriate for this content.
4. The content of the activity was accessible to most students in my class.
5. The activity helped my students meet the learning goals.

Table 1

Agreement about learning goals (in percents)

	Strongly agree	Agree	Neutral	Disagree	Strongly disagree
1. Addressed this class's learning goals	68%	31%	1%	0%	0%
2. I usually teach this content	64	27	7	1	0
3. Appropriate integration of graphs	78	22	0	0	0
4. Content accessible to most in class	74	22	2	1	0
5. Helped my students meet goals	72	26	2	0	0

Another question in the log asked teachers whether they would use that activity again. For 99% of the instances reported on the logs teachers said they would use the SmartGraphs activities again, either as is (63%) or with minor changes (36%).

When asked for more details about their experiences, teachers were overwhelmingly positive as illustrated by the quotes below:

> *I loved the program. Using the motion sensors and software really seemed to help kids wrap their minds around the graphs. Looking forward to doing it again next year!*
>
> *These kids did not need much prompting at all. Once they were shown how to use the sensors they ran with it. These students had fun with the software.*
>
> *I really like this whole project so far. I feel that 5 activities is a lot to incorporate into my curriculum while trying to stay on pace with the other 3 physical science teachers, and troubleshooting technology is always an issue, but I think my students are really getting a lot out of it.*

> *I gave a pure motion graphing test on Monday and I was really impressed by the quality of some of the students' level of understanding. In some cases it rivals some of our physics students. Motion graphing is a difficult concept and often hard for students to grasp.*

Learning Outcomes

Across 35 teachers, more than 2,000 students participated in the SmartGraphs research study. After eliminating students who only took one test (pre or post), there were 1,686 students (781 control students and 905 experimental students) who took both the pre- and post-tests. The reasons why students did not complete both tests were primarily that some students transferred classes or schools or were absent during one of the days the test was given by their teacher. The test had 8 multiple-choice (MC) questions (worth 1 point each) and 12 knowledge-integration (KI) questions (worth 4 points each), for a total of 56 possible points. For the analyses presented below, we used these weights for simplicity's sake, although we are considering other weighting schemes so as not to have such a wide discrepancy between the weights of the MC and KI questions.

All of the KI questions were scored by trained scorers, who were mostly graduate students in education. About 20% of the responses to each item were double-scored in order to compute inter-rater reliability and confirm consistency of scoring. The general KI rubric is shown in Table 2 (adapted from Lee & Liu, 2009). More specific rubrics were developed for each item individually.

Table 2

Knowledge Integration General Rubric

Knowledge-Integration Level	**Score**	**Response Characteristics**
Complex link	4	Students elicit and connect three or more normative and relevant ideas in a given science context.
Full link	3	Students elicit and connect two normative and relevant ideas in a given science context.
Partial link	2	Students elicit normative and relevant ideas in a given science context.
No link	1	Students elicit non-normative ideas or make invalid connections between non-normative ideas or between normative and non-normative ideas in a given science context.
Irrelevant	0	Students do not elicit ideas relevant to a given science context or do not provide a response.

Reliability was computed for both the pre- and post-tests using 1,686 students and all 20 items. Cronbach's alpha for the pre-test was .866, and Cronbach's alpha for the post-test was .886. This indicates that the results are reliable and would be consistent across test administrations. No item raised alpha more than .003 when deleted.

Table 3 shows student mean scores for the total test, the MC items alone, and the KI items alone on both the pre- and post-tests. The multiple-choice score was computed using the 8 multiple-choice questions, plus the multiple-choice parts of the KI items where applicable. Thus, there is a maximum of 15 points for the MC score. Both experimental and control students improved from pre to post on the total test score, on the MC items alone, and on the KI items alone, and the experimental students significantly outperformed the control students on all three measures. Because of the improvement from pre to post, we are confident that the test is sensitive to instruction.

Table 3

Results of Pre and Post-Tests

	Experimental		**Control**	
	Pre-Test	Post-Test	Pre-Test	Post-Test
Total Score	16.03	21.70	14.52	19.58
Multiple-Choice Score	6.85	8.77	6.36	8.27
Knowledge-Integration Score	12.34	16.93	11.08	15.08

To better compare the groups, gain scores were computed by subtracting the pre-test score from the post-test score. These results are shown in Table 4. The gain scores of the experimental and control groups are not significantly different for the total test gain score and the multiple-choice gain scores at the $\alpha = .05$ level, although the difference in total gain scores is approaching significance. The difference between the knowledge-integration gain scores is significant. Thus the difference between the groups lies in the experimental students' greater abilities to explain their answers, indicating greater depth of understanding, although the effect size of this difference was small (Cohen's d equal to .10).

Table 4

Gain Scores from Pre to Post Test

	Experimental	Control	Significance
Total Gain	5.67	5.06	t = -1.886, df = 1684, p = .059
Multiple-Choice Gain	1.92	1.90	t = -.145, df = 1684, p = .885
Knowledge-Integration Gain	4.59	4.01	t = -2.585, df = 1684, p = .049

Overall results confirm that the skills that SmartGraphs addresses are difficult for all students. For example, one multiple-choice item on the pre/post test asking students to calculate an average velocity based on a graph was only answered correctly by 49% of the control students and 62% of the experimental students after instruction on the topic. Clearly, there is much room for improved instruction to help students master these skills.

As we developed the software and the pre/post test, it was assumed that the fifth activity, Was Galileo Right?, would be used by all experimental teachers during the study. However as mentioned earlier, that was not the case. Therefore, some items on the test were related to learning goals not covered by any of the four SmartGraphs activities that were used by the teachers in the experimental group. To accommodate for this change in design, the pre/post assessment was re-analyzed by removing those unaligned items (three multiple-choice and one knowledge-integration item). After removing those items the test has 49 total possible points (the multiple-choice items had a maximum of 12 points and the knowledge-integration items had a maximum of 44 points). The gain scores for this reduced set of test items are shown in Table 5.

Table 5

Gain Scores from Pre to Post Test Excluding Four Items

	Experimental	**Control**	**Significance**
Total Gain	5.07	4.30	t = -2.669, df = 1684, p = .008
Multiple-Choice Gain	1.16	1.07	t = 1.973, df = 1684, p = .049
Knowledge-Integration Gain	4.19	3.64	t = -2.024, df = 1684, p = .043

In this analysis there is a significant difference in gains between experimental and control students for all three measures: total gain, multiple-choice gain, and knowledge-integration gain, all favoring the experimental students. Thus, the results are stronger when examining only test items that correlated specifically with the SmartGraphs activities that were used. Again, the effect sizes were small (0.13 for total gain, 0.10 for multiple-choice gain, and 0.10 for knowledge-integration gain).

Discussion

Based on analyses conducted to date, we conclude that, overall, teachers are happy with SmartGraphs, feel the activities are a valuable learning tool, and would use them again. We have observed a modest statistically significant difference in learning gains on open-response questions between students using Smartgraphs and those not using SmartGraphs, favoring the SmartGraphs students, indicating that SmartGraphs may have a positive impact on students' abilities to understand and explain these difficult graph understanding skills. In addition to the above results, we have observed that the experimental teachers taught the motion unit over 4.29 weeks on average (standard deviation of 2.45), while the control teachers took 6.50 weeks on average (standard deviation of 2.76). This time difference may be a noteworthy advantage of using SmartGraphs activities. Saving instructional time is one of the claims researchers have made in favor of using instructional technology (e.g., Fletcher, 2003).

Because students' scores are best understood as clustered data, the most appropriate method of analysis is hierarchical linear modeling (HLM). HLM is able to account for the similarity of students who have the same teacher, and will adjust standard errors accordingly. However since our gain scores were small, HLM was unlikely to reveal any additional information. Initial HLM analyses proved this to be true.

The SmartGraphs research will continue with the same teachers in the fall of 2012. Next fall, *all* participating teachers will use the SmartGraphs activities. The teachers will be divided into four groups, allowing us to answer several different research questions. This will help us to look more closely at which affordances of SmartGraphs are most beneficial to student learning about graphs. Continuing analyses and a second year of data collection will allow us to better determine what factors led to the differential gain observed during the first year.

References

Campuzano, L., Dynarski, M., Agodini, R., & Rall, K. (2009). *Effectiveness of reading and mathematics software products: Findings from two student cohorts*. Washington, DC: U.S. Department of Education, IES.

Dynarski, M., Agodini, R., Heaviside, S., Novak, T., Carey, N., Campuzano, L., et al. (2007). *Effectiveness of reading and mathematics software products: Findings from the first student cohort* (Report to Congress). Washington, DC: U.S. Department of Education.

Fletcher, J. D. (2003). Does this stuff work? A review of technology used to teach. *TechKnowLogia*, 5:1, 10-14.

Lee, H-S. & Liu, O. L. (2009). Assessing learning progression of energy concepts across middle school grades: The knowledge integration perspective. *Science Education, 94*, 665-688.

Monk, S. (2003). Representation in school mathematics: Learning to graph and graphing to learn. In J. Kilpatrick, W. G. Martin & D. Schifter (Eds.), *A research companion to Principles and Standards for School Mathematics* (pp. 250-262). Reston, VA: National Council of Teachers of Mathematics.

Murray, T. S., Kirsch, I. S., & Jenkins, L. B. (1997). *Adult literacy in OECD countries: A technical report for the first international adult literacy survey*. Washington, DC: National Center for Education Statistics.

NSF task force on cyberlearning (2008). *Fostering learning in the networked world: The cyberlearning opportunity and challenge*. Arlington, VA: National Science Foundation.

Rangel, E. S., & Linn, M. C. (2007). *Science education that makes sense* (Research Points #5:1). Washington, DC: American Educational Research Association.

Roschelle, J., Shechtman, N., Tatar, D., Hegedus, S., Hopkins, B., Empson, S., et al. (2010). Integration of technology, curriculum, and professional development for advancing middle school mathematics: Three large-scale studies. *American Educational Research Journal*, 47(4), 833-878.

U.S. Department of Education Office of Educational Technology (2010). *Transforming American education: Learning powered by technology*. Washington, DC: U.S. Department of Education.

Woolnough, J. (2000). How can students learn to apply their mathematical knowledge to interpret graphs in physics? *Research in Science Education*, 30(3), 259-268.

Zee, E. v., & McDermott, L. C. (1987). Investigation of student difficulties with graphical representations in physics. In J. Novak (Ed.), *Proceedings of the 2nd Int. Seminar "Misconceptions and Educational Strategies in Science and Mathematics"*, Vol. III (pp. 531-539). Ithaca: Cornell University.