Kinematics Card Sort Activity: Insight into Students' Thinking

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Kinematics is a topic students are unknowingly aware of well before entering the physics classroom. Students observe motion on a daily basis. They are constantly interpreting and making sense of their observations, unintentionally building their own understanding of kinematics before receiving any formal instruction. Unfortunately, when students take their prior conceptions to understand a new situation, they often do so in a way that inaccurately connects their learning. We were motivated to identify strategies to help our students make accurate connections to their prior knowledge and understand kinematics at a deeper level. To do this, we integrated a formative assessment card sort into a kinematic graphing unit within an introductory high school physics course. Throughout the activities, we required students to document and reflect upon their thinking. This allowed their learning to build upon their own previously held conceptual understanding, which provided an avenue for cognitive growth.[1] By taking a more direct approach to eliciting student reasoning, we hoped to improve student learning and guide our assessment of their learning.

Physicists use graphs as a second language and our students are often unable to "speak" that language due to a lack of conceptual understanding.[2] Students are proficient in graphing skills when they are able to apply learned patterns to memorize trends. However, when deeper interpretation of graphs is required, students struggle.[3] We believe this is, in part, because students' preconceptions are inhibiting their ability to form an accurate understanding of kinematic graphs. For example, once students learn one type of graph, they often incorrectly relate it to a newly learned type of graph. Additionally, students have difficulty separating the shape of a graph from the path of motion. When students see an upward sloping position-time graph, they often think it means the object is traveling uphill. Other studies have looked at different methods for teaching kinematic graphs,[4-6] but in this paper we focus on using a Card Sort activity to help make students' thinking explicit to themselves and their teachers.

Card sort activity

The activities were developed and implemented by a high school physics teacher (EB) who was part of the Target Inquiry graduate program at Grand Valley State University. These lessons stemmed from the struggles the teacher experienced directly when trying to teach kinematic graphing to her students in the past. Through the guidance of GVSU faculty, the lessons were developed and brought into the classroom as an action research project. Although card sorts are not new,[7] key to this one was requiring students to describe their reasoning. This allowed the students to build a conceptual understanding of kinematic graphs in a way that we had not seen historically when the activities were used on their own. The card sort was completed at three specific time points throughout the lesson sequence: after the first activity, after the second, and at the conclusion of the third activity. The card sort consisted of a total of 27 cards of which there were three types, as shown in Fig. 1.

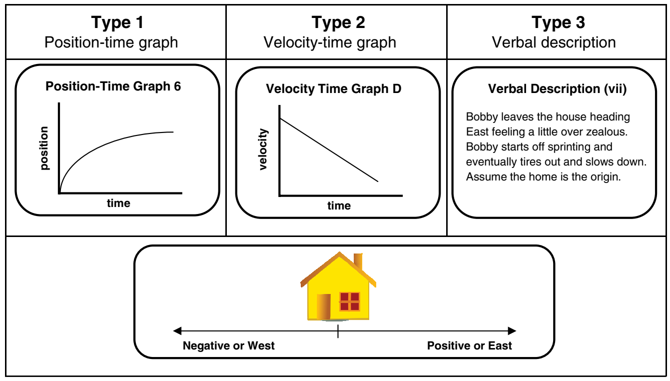


Fig. 1. Examples of card sort items.

Fig. 2. Students completing the card sort and documenting their thinking using the Google Form.

The students were also given a reference card to help visualize direction. Students grouped the cards into sets of three, one of each type. After grouping, students were asked to write a justification for their match by describing their reasoning. Students were not told whether their matches were correct until the final round. Each round contained the same exact cards to determine what changes students made to their original thinking. In order to promote dialogue and deeper thinking, the students completed the card sorts with a partner (Fig. 2).

At the end of round 2 and round 3, students also responded to the following question: "How has your thinking changed since the last card sort?" Using cell phones, students took pictures of their final matches and emailed them to their

Fig. 3. Students completing the Walk-Jog-Run Lab.

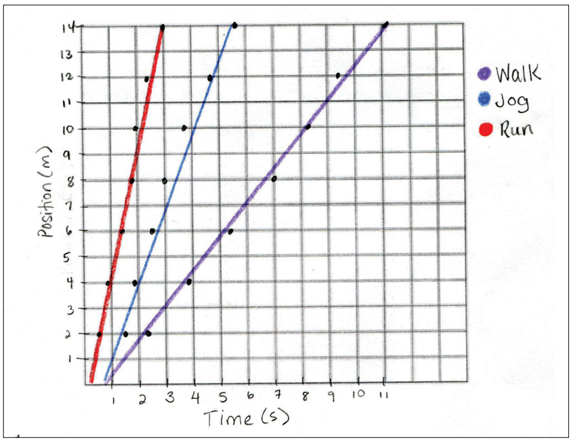


Fig. 4. Sample student work of the Walk-Jog-Run Lab.

teacher. Most students saved their photos in their phones, but as a backup the photos were uploaded to the class website. This allowed them to revisit the pictures later and easily compare how their thinking had changed between rounds. To make the card sorts less tedious, a Google Form was developed where students submitted their answers online. Typing answers saved time and students were more likely to elaborate. Additionally, since student responses were in a spreadsheet, they were much easier to analyze.

Lesson activities

The activities the students completed between each card sort were fairly standard kinematics labs we had modified so they were more aligned with the type of instruction called for in NGSS. The activities consisted of the Walk-Jog-Run Lab, the Toy Car Constant Speed Lab, and the Pull-Back Car Accelerated Motion Lab. In previous years, students did these activities as confirmation of what they had learned through in-class lecture. The previous versions were also very direct, with little student choice regarding how to conduct the lab or interpret data. Each revised activity focused on a question that students were trying to answer. The students learned the content *through* evidence collected in the lab before seeing any of the material in lecture format. At the end of each activity, students wrote an explanation where they made a claim, backed up their claim with evidence, and provided reasoning.[8] Each activity had extension questions that scaffolded students' development of key concepts and required students

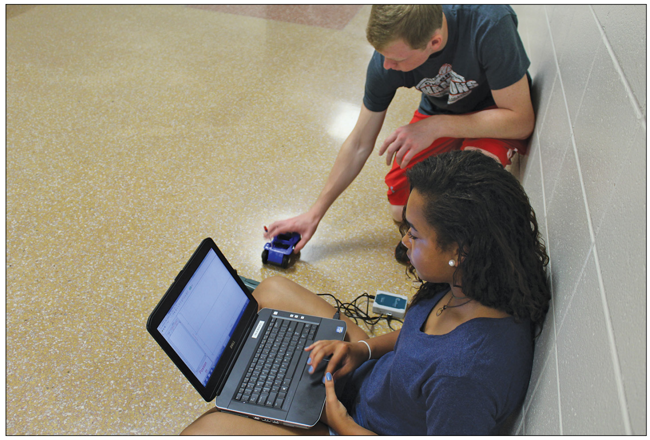


Fig. 5. Students completing the Steady as She Goes Lab using the constant speed toy car.

to interpret their data and share findings with the class.

In the first activity, Walk-Jog-Run (Figs. 3 and 4), students were tasked with answering, "How is speed represented on a graph?" The goal of this activity was to discover that the slope of a position-time graph represents velocity. In both the second and third activities, Steady as She Goes (Fig. 5) and Kinematic Kopy Kat, students used motion sensors and toy cars to answer, "Does my car travel at a constant speed?" Velocity-time graphs were introduced in these lessons with the goal of helping students understand the differences between how constant speed and accelerated motion are represented graphically. In between each activity, students completed the card sort as a means to check in with themselves and the teacher. A full description of each activity, including sample student data and teacher facilitation tips, can be found at the following website: http://www.gvsu.edu/targetinquiry.[9] Alternatively, the cards for the card sort activity can be found as an online supplement to this article.[10]

Outcomes

Integrating the card sort throughout these lessons made a substantial difference, both for the learner and the instructor. Requiring students to elaborate on their thinking was exceptionally informative. Unlike the past where students often tried to memorize patterns, requiring students to explain their reasoning encouraged them to think carefully about their choices. This made them less likely to make random guesses and pushed them to connect meaning to kinematic graphs. As students began to elaborate on their thinking, they often caught many of their own incorrect ideas. In confronting their misconceptions, students built a more solid understanding of the concepts. The students showed gains from each successive round of the card sort as shown in Fig. 6. The largest gain took place after the Steady as She Goes Toy Car Lab, with a 23% gain in their percentage of correct matches.

In addition to the card sort, students took a pre-test before the lesson sequence and a post-test at the end of the third activity. The questions were selected from the Test of Understanding Graphs in Kinematics: TUG-K.[2] Only questions

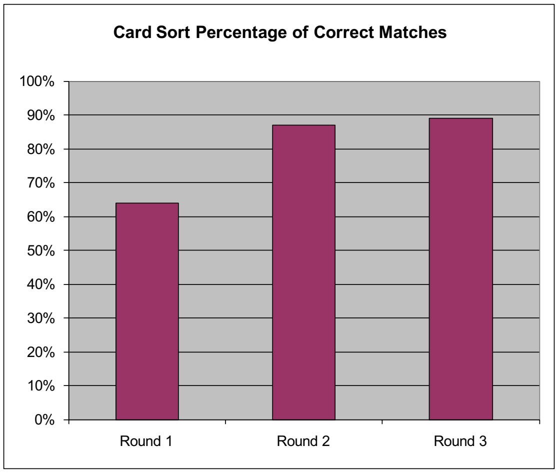
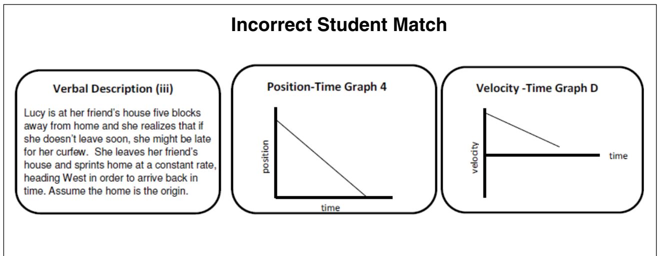


Fig. 6. Student gains are demonstrated for each round of the card sort (*n* = 43 student pairs).



Example 1 of Student Reasoning: Lucy is starting away from the origin and sprints at a constant rate back home, heading in the negative direction. The slopes of both graphs are negative and headed back to the origin.

Example 2 of Student Reasoning: Since Lucy is at a friend's house she starts farther away from the origin. Then, once she needs to go home she heads back in the west direction and is sprinting home, which means the line would have a steep slope. Graph 'D' goes with these because she is going back to her house which is the origin.

Fig. 7. Student reasoning for incorrectly matching Graph 4 with Graph D provided insight into a student misconception about the origin on velocity-time graphs.

After Activity 2, how has your thinking changed?
Example 1 of Student Response: We have realized that the zero on the velocity graph has nothing to do as far as where the home is concerned.
Example 2 of Student Response: Originally we thought the vertical axis [on velocity time graphs] was representing the distance away from the house...When in reality, the vertical axis represented how fast the person was going. The zero meant they weren't even moving, and the farther away from the origin you got, the faster the person was moving.

Fig. 8. Student responses indicate that students recognize their misconception regarding origin on velocity graphs after answering, "How has your thinking changed?"

in line with the lesson objectives were selected, consisting of a total of 12 questions covering four of the seven TUG-K objectives. Table I provides a comparison of our students'

Table I. Comparison of pre-post TUG-K results with TUG-K study data.

	Percent correct		
Objective	**Pre-test results** (*n* = 93)	**Post-test results** (*n* = 93)	**TUG-K study results** (*n* = 524)
1. Given a position-time graph the student will determine velocity.	29	43	51
5. Given a kinematics graph, the student will select another corresponding graph.	15	46	38
6. Given a kinematics graph, the student will select a textual description.	22	49	39
7. Given a textual motion description, the student will select a corresponding graph.	22	56	43

outcomes with those from the TUG-K study. The TUG-K study tested high school and college physics students after receiving instruction in kinematic graphs. Our students made the greatest gains (27-34%) on objectives that were qualitative in nature (Objectives 5, 6, and 7) and a smaller gain for Objective 1, which was more quantitative. These results are consistent with the lesson sequence as the activities were much more conceptual and did not focus on computational applications of kinematic graphs.

The information obtained from the card sorts provided profound insight into students' difficulties with kinematic graphs. For example, students did not equate the origin on a velocity-time graph with the object being at rest. Rather, students assumed that the origin on the velocity-time graph correlated with the origin for position (in this case, home). Figure 7 is an example of an incorrect match that 20% of students made during round 1, along with examples of student reasoning. Without the student reasoning, we would not have known why students made this mistake. After round 2 and round 3 of each card sort, students were asked, "How has your thinking changed?" This encouraged students to reflect on their thinking and in turn highlighted many of their misconceptions for them. This afforded students the opportunity to learn from their mistakes on their own and develop a more solid understanding of the concepts. Figure 8 gives several examples of how students recognized that the Steady as She Goes activity caused them to change their thinking and realize that the origin on a velocity-time graph is not related to a particular position.

The mere requirement of asking students to explain their reasoning provided insight into the students' thinking that had not been seen in such a direct way before. As a class, we were able to pause and have a rich discussion about the common mistakes students were making and, more importantly, *why* they were making these mistakes. The insights from the card sorts enabled targeted re-teaching. For example, the class talked at length about the importance of identifying what each axis represents *before* interpreting a graph. This is a skill students can apply beyond physics class.

The card sorts clearly highlighted common misconceptions with kinematic graphs. It may be tempting to use this knowledge to modify future instruction in a way that front loads the information so the students avoid making mistakes in the first place. However, this card sort showed how valuable it was for students to uncover these misconceptions on their own. Wrestling with the concepts and continually reshaping their understanding as they progressed through the lessons allowed students to learn the content more thoroughly. In the past, the students were not pushed to explain their thinking in such a visible way. Class discussions attempted to elicit student thought, but rarely were students required to write down their thinking. The card sort and TUG-K results indicate that using student reasoning throughout instruction improves student learning. These positive results and the ease by which students were able to document their thinking (via the online form) makes this an easy and effective tool that we hope to utilize in other areas of instruction going forward.

Acknowledgment
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9. You must first create an account by clicking on "Click here to access teacher materials." Once your account is confirmed, you will have access to these lessons as well as many more developed by teachers in this program. This lesson sequence can be found by searching for "kinematics."
10. See [supplementary material] for a set of cards for the Student Card Sort Activity available under the "References" tab at *TPT Online,* http://dx.doi.org/10.1119/1.4967894.

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