Use of Collaborative Computer Simulation Activities to Facilitate Relative Motion Learning

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Abstract

Through statistical methods and analysis of protocol, we investigated how secondary students' interaction with two different sets of simulation activities could affect relative motion problem solving and mental model construction.

Though learning occurred in both treatment conditions, students who saw only animations did not perform better on a measure of relative motion understanding than students who received only numeric feedback. Interview protocol provided evidence of conceptual change fostered by interaction with the activities.

We hypothesize a framework for understanding relative motion model construction in which visual and numeric models may co-exist and be integrated into a resultant mental model.

Keywords — secondary science education, physics, collaborative learning, computer simulation, conceptual change, mental models, visualization, problem solving.

1. Introduction

Several research programs have documented students' difficulties with learning relative motion. (See [9, 10] for reviews.) Recently, research programs have investigated the use of computer simulations to assist conceptual change. (See [4, 7, 8, 14, 15] for reviews.) At SRRI, we identified several relative motion alternative conceptions and have been investigating ways that collaborative computer simulation activities can assist secondary students in learning relative motion [9, 10].

In this paper, we report results from three studies in which students' performance using collaborative computer simulation activities was examined. Statistical methods were used to explore whether interaction with collaborative computer simulation activities improved scores on a measure of relative motion understanding. Analysis of student protocols was used to explore how interaction with the activities could affect relative motion mental model construction.

2. Study Descriptions

In the studies, predict-observe-explain activities (see [8]) were designed to encourage interaction with anomalous events (see [2, 11, 13]), and to slowly build students' understanding of relative motion. Since the students had not previously studied relative motion, all diagnostic problems (pretest/posttest) and all simulation activities involved one-dimensional relative motion (i.e. all motion was left to right or right to left). In the first simulation, initial motion was in one direction to avoid overwhelming the students. Also, all screen objects were "iconic" (see [14]) to facilitate transfer.

In the studies, high school science students, working in pairs, interacted with four computer simulations presented in a predict-observe-explain format. Two treatment conditions were used — conditions DN (decontextualized numeric) and CV (contextualized visual). We had previously constructed the simulations using RelLab [6] relativity laboratory software that had been modified using ResEdit [1].

In the CV treatment, for each of the four simulations, pairs of students were given screen snapshots with labels added to the screen snapshots (see figure 1). The students were then shown an animation of an event. They were asked to predict the direction of travel of the objects relative to a new frame of reference, to supply a reason for each prediction, and to indicate their confidence in their predictions. Following their predictions, the students were shown the event from the new frame of reference. They then provided an explanation for any discrepancies between their predictions and their observations.

The DN students interacted with the same 4 simulations. However, the DN students received numeric information (a numeric speed and numeric direction), rather than animations. Their predictions concerned the speeds of objects relative to the reference frame.

The DN students' screen snapshots did not contain context labels (e.g. dog, person on bike, pyramid).

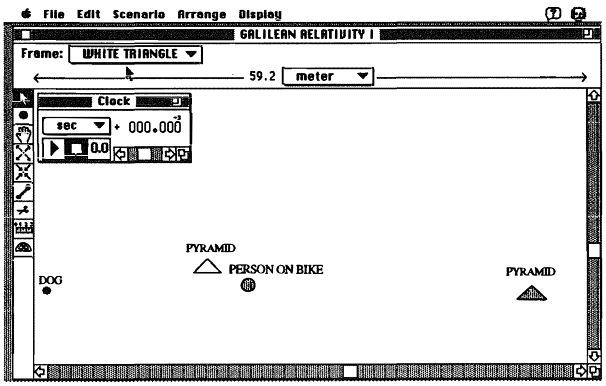


Figure 1. Screen snapshot with labels added (CV).

The authors of RelLab software, which received the 1992 EDUCOM national award for Best Natural Science Software (physics), advocate a more student-centered open-ended inquiry approach to using RelLab [7]. We constrained the interface and the activities to facilitate systematic observation of student learning processes.

3. Statistical Results

In the first study, two entire standard level physics classes taught by the same teacher in a large religiously affiliated high school were involved. One class received the CV treatment (CVstd); the other did not receive a treatment (control std). In the second study, two entire honors physics classes taught by a second teacher in the same school were compared. One class received the contextualized visual treatment (CVhon group); the other received the decontextualized numeric treatment (DNhon group). Statistical results are summarized in table 1.

Table 1: Classroom one tailed t-test results: Posttest/pretest and gain comparisons

group	n	pretest mean	posttest mean	p	mean gain	p
CVstd	19	36%	47%	<.01	11%	<.10
control std	22	45%	49%	N.S.	4%	
CVhon	19	58%	68%	<.05	10%	N.S.
DNhon	16	58%	72%	<.01	14%	

We expected the CVhon group to perform better on the measure than the DNhon group, hypothesizing that the animation combined with a recognizable context would make the simulation easier to apply to problems. We expected the CV condition to foster visualization and expected visualization to assist problem solution. However, five of nine test questions requested a numeric answer; some students may be able to calculate answers to these questions without visualization. Also, it is possible that some students were able to take numeric information provided by the DN condition and convert it to a visual representation. This skill could then be applied during problem solution. This may be particularly true for honors students who may be fluent in their use of numeric representations. Also, based on examination of students' predictions, the CV predictions were easier than the DN predictions. The CV condition may have been sufficiently easy for students that little dissonance and little learning occurred.

In the third study, 16 public secondary standard level chemistry student volunteers were involved in videotaped clinical interviews. (4 pairs received the CV treatment; 4 pairs received the DN treatment.) Below, a case study of a pair of CVchem group students provides evidence for conceptual change following participation in the collaborative predict-observe-explain activities. The case study also provides some evidence on how students may construct mental models of relative motion problems.

4. Case Study

4.1. Pretest

Protocol evidence for difficulties with relative motion pretest problems are displayed below. Student ac1 apparently ignores the effect of the motion of the reference frame on the answers for problems 7 and 9.

ac1: (question 7 — see figure 2)...if the barge is going to the left at four miles per hour, and the barge worker's walking in the opposite direction, then um, in relation to the, to the cruise ship, the um, barge worker is just staying at the same place. So it's zero miles per hour [correct answer is 10 mph]. Because um, because the barge worker is sort of evening off how far the barge has gotten away from the cruise ship.
...And I'm fairly confident in my answer.

(question 9 — see figure 2) ... the barge worker is walking towards the right, and Joe is facing the bar, barge worker. ... to keep him in his, in the telescope range, then he has to move the telescope to the right [correct answer is to the left], ... with the barge worker.

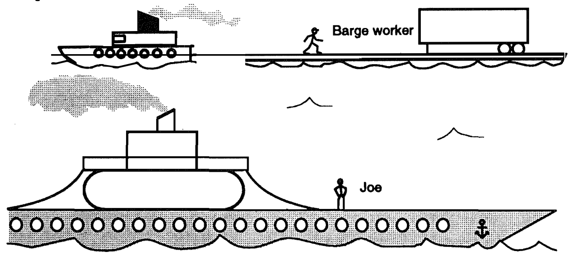
4.2. Treatment

During simulation activity 1, ac1 expresses surprise with apparently unexpected output of the computer simulation . ac2 appears to assist ac1 in understanding the simulation output, as indicated in the following protocol:

ac1: Why isn't the bike [frame of reference] moving?

ac2: If we're, I would think that if we were in like the focus of, we're on the bike, um, and you're

Joe is watching a barge from the deck of the cruise ship. The barge is being pulled by a tugboat at a speed of 4 mph, relative to the still water. A barge worker is walking toward the back of the barge at a speed of 4 mph, relative to the barge. The cruise ship is traveling at 10 mph relative to the still water.



7. What is the barge worker's speed relative to the cruise ship?
a) 6 mph b) 10 mph c) 4 mph d) 0 mph e) 8 mph
8. How confident are you in your answer? ...
9. Joe is viewing the barge worker through a telescope. To keep the barge worker in the center of his vision, which way must he move the telescope?
a) to the left b) to the right c) neither

Figure 2. Pretest/posttest questions 7-9.

looking down [points down with pen in right hand], we're going [moves right hand to the right] along with the bike so it doesn't look like it's [the bike] going.

ac1: Oh, OK. Right so then we pass pyramids, and then the dog passes us [moves right hand back and forth].

ac2: The dog passes us.

During the above interaction, both students appear to employ dynamic mental imagery (see [3, 5]), evidenced by hand motions, reports of self-projection, and the report of multiple states of the scenario. We hypothesize that such mental imagery during the treatment may assist students in visualization of relative motion problems when the computer simulation is absent (see [9] for a similar result).

4.3. Posttest

Ac1 apparently made substantial gains in her understanding of relative motion. Her posttest score on the 9 question test was 77%, compared with 11% on the pretest. For example, problems 7 and 9 revealed accurate reasoning.

ac1: (see figure 2) ... well the cruise ship is traveling to the right... ten miles per hour, and the barge worker's traveling to the right at four miles per hour, but the, um, barge is going to the left at four mile per hour. .. ...they'd [barge worker and the barge] both um, even each other off ... the barge workers' speed relative to the cruise ship would be ten miles per hour....

Similarly, her answers to several other posttest questions revealed an understanding of relative motion that had not been displayed during the pretest.

Below, she refers to the influence of the computer simulation on her solution.

ac1: I'm not sure if, if it was like the computer um, where if the um, cruise ship is ...the fix thing that ...stays still, or that is looks like it stays still, but it's really going ten miles to the, per hour to the right, then I think the uh, if the ship looked like it was staying still, then the barge worker would be going ten miles to the left, um, in respect to the ship.... on this [computer] screen or whatever, it's [the cruise ship] stayin' still...

Following a very short treatment, ac1 showed substantial gains in her ability to solve relative motion problems; she clearly and accurately transferred experiences with the collaborative simulation activities to transfer problems. It appears that the activities assisted her with visualization, providing a template for her visualization of transfer problems. (For a similar result, see [9]) Subject ac1, who made substantial gains on the posttest, was aided in her understanding of simulation 1 by ac2. It is conceivable that the cognitive effort expended by ac1 in her attempt to understand the anomalous data triggered conceptual change (see [2, 11, 13]). However, ac1's partner, ac2, did not display substantial gains, scoring 33% on both the pretest and posttest. It is plausible that this was due to insufficient experience with the collaborative simulation activities. Or, the presented activities were not at the appropriate level for her to advance her current conceptions.

5. Mental Model Construction

We hypothesize that students often construct a mental model of a relative motion problem through parallel construction of a visual model (see [15]) and a numeric model. The generation of the visual model is done by constructing a visual model of the motion of objects, relative to each medium which motion occurs in or on, and coordinating the components. (see [5] for a similar hypothesis.) In parallel with visual model construction, the student may construct a numeric model of components of the problem and combine the numeric components. The visual model and the numeric model are subject to criticism based on a student's epistemological commitments (e.g. the "true" velocity of an object is its velocity relative to the ground (see [12]). If both the visual model and the numeric model pass the epistemological commitment tests, they are combined into a resultant mental model. A clash between the visual and numeric models may cause reconstruction of either model, based on the student's confidence in the models. It is possible, however, that the student will be unconcerned with, unaware of, or unable to resolve inconsistencies between the models. (See [2].) In figure 3, the hypothesized processes of relative motion model construction are shown. Arrows reveal potential flow of mental processing.

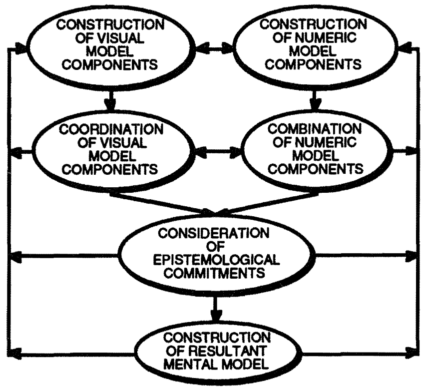


Figure 3. Relative motion model construction processes.

As an example, consider subject ac1's solution of problems 7 and 9. In her posttest protocol, she incorporated the movement of the cruise ship (relative to the ground) into her model of the problem. We hypothesize that this was done in part because the student had changed an inaccurate epistemological commitment present during the pretest, namely that the barge worker's motion is independent of the motion of the cruise ship. Additionally, it appears that experience with the collaborative computer simulation activities affected the student's visual model of the problem, as she referred to the cruise ship as equivalent to the still object on the computer screen. This analogous reasoning may indicate improved understanding of the reference frame concept, a necessary prerequisite for accurate mental imagery of the problem. We further hypothesize that critical to, and concurrently developed with her visual model, is her numeric model of the problem. Without an understanding of the numeric information present in the problem, she would be unable to produce a unique visual model of the problem; her visual and numeric models evolve in parallel, we hypothesize.

In ac1's pretest protocol , there is an inconsistency between her visual and numeric models of the problem. Her response that the barge worker was traveling 0 mph relative to the cruise ship, is inconsistent with her response that the barge worker was moving to the right relative to the cruise ship. This inconsistency is an indication that the two models (visual and numeric) are separate. It appears that consideration of the aforementioned epistemological commitment affected her construction of models.

6. Conclusions and Discussion

We provided preliminary statistical and protocol evidence for the efficacy of short, highly constrained, collaborative computer simulation activities for improving performance on a measure of relative motion understanding. Thus, collaborative computer simulation activities may be able to assist students' learning in difficult domains like relative motion. As evidenced by ac1's performance on relative motion problems which required directional answers (like question 9) and numeric answers (like question 7), it appears that simulation activities, in which only visual information is presented, can assist students in solving both directional and numeric problems.

We provided evidence for collaborative activities fostering significant progress for one student, and little or no progress for her partner. Thus, in a domain where alternative conceptions frequently are evident, varied activities, and varied strategies, may be required to assist different student's conceptual change (see [2, 4, 14]).

Acknowledgments

This research was supported by NSF. Opinions expressed are those of the authors and not necessarily of NSF.

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