Newton's Third Law in Middle School

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Newton's Third Law is a difficult concept to teach well, and middle school students' ideas are mediated by their teachers' conceptions as well as their lived experiences. As part of a school-year course for in-service middle school using inquiry techniques with teachers, eighth-grade science teachers studied Newton's Third Law and how to facilitate their students' learning of it, and taught their students. In this study, we self-assessed the teachers' learning of Newton's Third Law the first year of the middle school program, and they assessed their students using a similar instrument the next two years. From student gains, we compare teachers' ideas and their students' learning.

Introduction

In 2003-2004, Aubrecht was part of a team that won a Department of Education grant, known as IMPACT (Inquiry Model for Professional Action and Content-rich Teaching). We worked with K-12 teachers in Marion and Newark, Ohio, helping them rethink how they were teaching, helping them ask more (and better) questions. Some of the teachers were from the middle school in Marion, Ohio. They contacted the administration of the City Schools and suggested that he be involved in improving science scores at the middle school level—at Grant Middle School in Marion, Ohio.

Aubrecht submitted a seed grant proposal to the Ohio Department of Education that was funded. We had teacher buy-in; the union agreed and each teacher agreed to be part of the program. He submitted a full proposal, with the title "Systemic Change Through Embedded Professional Development at a STEM+C Middle School (IMPACT II)," which has been funded for two years so far. Our program involves teachers in hands-on activities and building better questioning strategies with teachers.

The Marion City Schools (MCS) have a difficult task. About three-quarters of the students get free or reduced-cost lunches. The student "churn" is about 25% per year. Students in the Marion City Schools do not score well on Ohio's proficiency tests.

Most teachers told us that before the program began, either they believed that teaching is telling and that students must remain under strict control, or had moved to that as the "easiest" way to fit in at the school.

Our goals are to enable honoring of student questioning and inquiry from middle school science teachers. Control in inquiry resides much more with students themselves, which is initially scary for the teachers because of the emphasis on teacher control in the public schools.

The program began in summer 2008, with the teachers meeting for two weeks just before school began. During the school year the first year of the program, we met with teachers two periods for each grade level per week. There was an optional summer class the second year, and we met with the teachers more sporadically the second year due to a funding decrease. However, we did have three all-grade meetings spread over the school year and enabled and supported teacher-directed professional development activities.

Eighth Grade and Newton's Third Law

Eighth grade in Ohio is traditionally where students are exposed to the formal concept of force. Grant Middle School adopted FOSS, (1) which has inquiry components, simultaneously with our program to help teachers transition to inquiry. Part of our initial training was in acquainting teachers intimately with the FOSS units. One of the FOSS units chosen for eighth grade is "Force and Motion." Because of Ohio Standards (and because we believe it's important), this unit was part of what we used in this class.

There were six teachers of eighth-grade science during the first year. Three were regular classroom teachers, who were all also there the second year, and three were special education teachers of various stripes who were not present the second year due to changes instituted by the school administration.

Aubrecht and his collaborator, Bill Schmitt of the Science Center of Inquiry, visited teachers for an hour twice a week during the program's first year during their grade-level preparation periods, and less often the second year. These sessions were devoted to determining problems with implementation of FOSS, ideas the teachers themselves had for investigations, and content material learning for the teachers.

During meetings with eighth-grade teachers in late 2008 and early 2009, the FOSS module "Force and Motion" implementation was being worked on by the teachers and the staff. It is well known that Newton's Third Law causes challenges for students. (2-9) We decided to examine teachers' and students' ideas on Newton's third law. In one of our meetings, Aubrecht asked the teachers the questions developed by Ellie Sayre (2) (Table 1).

Table 1. Six questions on Newton's Third Law

1. A car and a truck are moving at equal speeds towards each other. The truck weighs much more than the car. Consider the forces that they exert on each other at the moment they hit.
A. The truck pushes on the car more than the car pushes on the truck.
B. The truck pushes on the car exactly as much as the car pushes on the truck.
C. The truck pushes on the car less than the car pushes on the truck.

2. Two cars are moving towards each other at unequal speeds. The two cars have the same mass. Consider the forces that they exert on each other at the moment they hit.
A. The fast car pushes on the slow car more than the slow car pushes on the fast car.
B. The fast car pushes on the slow car exactly as much as the slow car pushes on the fast car.
C. The fast car pushes on the slow car less than the slow car pushes on the fast car.

3. A car is pulling a trailer that weighs a lot more than the car. The car speeds up. Consider the forces that they exert on each other while they speed up.
A. The trailer pulls on the car more than the car pulls on the trailer.
B. The trailer pulls on the car exactly as much as the car pulls on the trailer.
C. The trailer pulls on the car less than the car pulls on the trailer.

4. The same car and trailer now move at constant speed. The trailer still weighs more than the car. Consider the forces that they exert on each other while they move at constant speed.
A. The trailer pulls on the car more than the car pulls on the trailer.
B. The trailer pulls on the car exactly as much as the car pulls on the trailer.
C. The trailer pulls on the car less than the car pulls on the trailer.

5. The trailer is now hitched up to a truck. The truck and the trailer weigh exactly the same as each other. The truck speeds up. Consider the forces that they exert on each other while they speed up.
A. The trailer pulls on the truck more than the truck pulls on the trailer.
B. The trailer pulls on the truck exactly as much as the truck pulls on the trailer.
C. The trailer pulls on the truck less than the truck pulls on the trailer.

6. The truck and trailer now move at constant speed. They still weigh exactly the same as each other. Consider the forces that they exert on each other while they move at constant speed.
A. The trailer pulls on the truck more than the truck pulls on the trailer.
B. The trailer pulls on the truck exactly as much as the truck pulls on the trailer.
C. The trailer pulls on the truck less than the truck pulls on the trailer.

The correct answer is of course B in all cases, as we recognize from Newton's Third Law. Teachers' first responses are shown in Table 2.

Table 2. Teachers' initial responses to questions

	1	2	3	4	5	6
Teacher 1	A	B	A	C	C	B
Teacher 2	B	B	B	B	B	B
Teacher 3	A	B	B	C	A	A
Teacher 4	B	B	A	B	B	B
Teacher 5	A	A	A	A	B	B
Teacher 6	B	B	C	B	C	B

Clearly, teachers disagreed. Aubrecht did not talk about a "right" answer. Instead, he asked the students to break into two groups of three and discuss the matter among themselves. Interestingly, after extensive discussion, the teacher who answered all "B" was persuaded by his peers to abandon his position. Aubrecht ended the session by asking all teachers to think about the answer in the meantime.

For the following class, Aubrecht reminded teachers of their answers (in summary form, Question 1 3 A, 3 B, etc.) and asked teachers how they would answer the questions if the word velocity were used in place of force, and answers were changed to read, for example, "the velocity of the car was greater than that velocity of the trailer." After polling students, he ascertained that the answers to the six modified questions seemed to be essentially the same as the answers when "force" was at issue. He asked whether force was the same as velocity. After further discussion, students asked to be reminded about what force was; Aubrecht, after defining force, asked them if velocity and "change of velocity" (as a part of acceleration) had to be the same. The teachers said that they would NOT expect that to be so. Eventually, by these means—but not by telling them—teachers came to the realization that they were thinking about changes in velocity, not about the force. They were in a better place to begin teaching the subject.

What happened when teachers taught Newton's Third Law to their students

First Year - As discussed above, three of the six eighth-grade teachers were lead classroom teachers. Here, we will denote them A, B, and C. During the first year of the program, one teacher (Teacher A) did not keep any data, despite Aubrecht's request.

One teacher (Teacher B) forgot that Aubrecht wanted the data and threw away the data but kept a summary, which was shared with us. This teacher's anecdotal data showed that the one question with the car pulling the trailer that has a larger mass stood out as the most misunderstood question. Table 3 presents these data.

Table 3. Important points from the Teacher A summary (first year)

N	Improvement	No Improvement	Decreased Knowledge	All Correct
87	37	32	18	5

One teacher (Teacher C) spent just two days of instruction on force (including Newton's Third Law). The teacher kept meticulous data, but saved only the overall data, so no comparable comparisons were possible. Table 4 presents these data. This small a time of instruction reveals no change in student understanding.

Table 4. First year data from Teacher C

Before					
1	2	3	4	5	6

A	51	40	23	19	8	7
B	9	18	19	24	25	45
C	1	3	19	17	27	9
	15%	29%	30%	38%	38%	67%

	After					
	1	2	3	4	5	6
A	52	39	26	22	10	9
B	9	19	12	29	24	38
C	0	3	23	10	27	14
	15%	30%	19%	45%	36%	57%

Second Year - During the second year, all three teachers kept their pretest data, and two kept their posttest data.The teachers had greater success than the first year. Table 5 shows these data. “Comparable only” denote students who could be identified between before and after questions (Some students were absent and some used different identifiers between the two). Questions 1 and 3 were the ones the fewest students answered correctly prior to instruction. We infer that this indicates that students believe that mass is an important determinant of the force exerted. Most students know that football players “bulk up” to be more effective and may think that that means that they can exert a greater force rather than that their momentum changes less in a collision. Some students use this ad hoc model to address these questions.

Question 6 had the greatest proportion of correct answers prior to instruction. Because of question 5, we may presume that it is the constancy of the speeds that lead students more often to the correct answer in question 6.

Table 5. Student data from year 2 (N_{max} = 78, 81, 68, and 15 for Teachers A, B, C, and college, respectively; for comparison, the N are 62, 62, 0, and 14, respectively).

	Before					
	1	2	3	4	5	6
Teacher A	18%	35%	14%	49%	50%	61%
Teacher B	23%	11%	19%	51%	40%	75%
Teacher C	28%	26%	24%	57%	30%	65%
College	20%	45%	30%	60%	55%	85%

Comparable Only						
	1	2	3	4	5	6
Teacher A	15%	34%	13%	51%	48%	63%
Teacher B	24%	11%	21%	56%	44%	77%
Teacher C	—	—	—	—	—	—
College	21%	43%	36%	64%	64%	79%

	After					
	1	2	3	4	5	6
Teacher A	45%	47%	31%	56%	62%	65%
Teacher B	71%	75%	76%	77%	73%	82%
Teacher C	—	—	—	—	—	—
College	47%	20%	53%	80%	73%	93%

Comparable Only						
	1	2	3	4	5	6
Teacher A	48%	55%	34%	61%	66%	73%
Teacher B	69%	69%	72%	74%	66%	81%
Teacher C	—	—	—	—	—	—
College	50%	21%	50%	79%	71%	93%

The table shows that the middle school teachers' students had greater success in answering the questions correctly after instruction. In fact, 10 students in Teacher A's class and 46 students in Teacher B's class a answered completely correctly.

Table 5 also shows that Aubrecht's physics students taking the algebra-based course had similar ideas to middle school students prior to instruction. The college students showed gains for all questions but number 2. It is unclear what instruction did to decrease correct answers to this question while increasing correct answers substantially to the other questions.

Conclusions

It appears from these data that student models of forces can be changed in a way that increases internal consistency.

Aubrecht is currently considering how to alter instruction on Newton's Third Law in his algebra-based physics course because of the results from question 2. This shows the value of such questions for formative assessment at college; we are of the opinion that it can serve the same purpose at middle school. As a result of this study, we have instituted formal formative assessments for the classes of the teachers in the program and encouraged the teachers to analyze students' ideas (10).

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References

Aubrecht, G. J. (2012). "A project involving American middle & high school science teachers, asking them to *change,"* invited talk, teacher program, World Conference on Physics Education, Istanbul, 6 July.

Bao, L., Hogg, K., & Zollman, D. (2002). "Model analysis of fine structures of student models: An example with Newton's third law," *Am. J. Phys.,* **70**, 766-778.

Brown, D. E. (1989). "Students' concept of force: the importance of understanding Newton's third law," *Phys. Educ.* **24**, 353-358.

FOSS is a research-based science program for grades K–8, developed by the Lawrence Hall of Science, University of California at Berkeley. FOSS is an acronym for Full Option Science System.

Maloney, D. P (1984). "Rule-governed approaches to physics-Newton's third law," *Phvs. Educ.,* **19**, 37-42 (1984).

Maloney D. P., & Boyle, R. K. (1991). "Effect of written text on usage of Newton's third law," *J. Res. Sci. Teach.,* **28**, 123-139 (1991).

Meltzer, D. E. (2005). "Relation between students' problem-solving performance and representational format," *Am. J. Phys.,* **73**, 463-478.

Poon, C. H. (2006). "Teaching Newton's third law of motion in the presence of student preconception," *Phvs. Educ.* **41**, 223-227.

Sayre, E. C. Franklin, E. C., Dymek, S.V., Clark, S., & Sun, Y. (2012). "Learning, retention, and forgetting of Newton's third law throughout university physics," *Phys. Rev. Sp. Topics PER,* **8**, 010116 1-10.

Smith T. I. & Wittmann, M.C. (2007). "Comparing three methods for teaching Newton's third law," *Phys. Rev. Sp. Topics PER,* **3**, 1-8.