A summary of students' mental models and their applications in contexts pertaining to Newton's II law

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Abstract

We investigated students' use of Newton's II law in mechanics and electricity and magnetism contexts. We interviewed 16 students in a two-semester calculus-based physics course. We found students' answers are consistent with two principal mental models and a combination of these two. We explore whether the students who use Newton's Second Law in mechanics contexts continue to do so in electricity and magnetism.

Introduction

Students use various knowledge structures (or mental models) to make sense of situations.[1] Students build these knowledge structures from information based on prior experience or through instruction. Researchers have been probing students' mental models to better understand the origin of student difficulties.[2] In this paper we present a summary of our ongoing research on how students' knowledge structures are consistent or not with Newton's II Law in mechanics, electrostatics and magnetism contexts.

Goal & Methodology

We attempted to address the following research questions:

- What knowledge structures (mental models) do students in calculus-based introductory physics courses use to describe motion?
- How do these knowledge structures change with contexts as students progress through a two-semester course sequence in contexts in mechanics and electricity and magnetism?

We interviewed 16 students in a calculus-based physics class six times over two semesters. The class operates with two 1-hour lectures and a two-hour lab integrated with the recitation (Studio). The interviews were conducted at the beginning, middle and toward the end of each semester. The first interview was conducted before Newton's Laws were introduced in class. We present preliminary results from our interviews. We will discuss these and other results in a forthcoming paper.

Instruments: Semester I

Our first semester interview protocol is partly based on questions from the Force Concept Inventory (FCI).[3] Interview 1 addressed two contexts, which we label "vertical" and "horizontal." The vertical context is based on FCI question # 17:

An elevator is being lifted up an elevator shaft at constant speed by a steel cable.

- What is the force in the cable when the elevator is at rest, moving up, or down at constant velocity?
- What is the force if the velocity is doubled?
- What is the force if the velocity is steadily increasing?
- How does the velocity change if the force is doubled?
- What force is needed to move an elevator, twice as massive at the same velocity?

The horizontal context questions were based on FCI questions # 25 through 27:

A woman exerts a constant horizontal force on a large box. As a result, the box moves across a horizontal floor at a constant speed.

- How does her force compare with friction?
- What force does she need to double the velocity?
- What force is needed to steadily increase the velocity?
- How will the velocity change if her force is doubled?
- What force is needed for two boxes with the same velocity?
- What happens if she stopped pushing?

In Interview 2 we explored the same vertical and horizontal contexts with other physical features, *i.e.* changing from pushing to pulling and from lifting to hauling. We also changed from a person to a mechanical device performing these activities. In Interview 3 we explored contexts that included Atwood's machines. Based on research by

McDermott [4], we believe that these contexts pose special difficulties to students. The questions asked on this interview were similar to those asked in the first interview.

Results & Discussion: Semester I

Student responses on all of the questions were consistent with either of the following mental models --- the Newtonian model ("F = ma.") or Aristotelian model ("F = mv"). Students whose responses are consistent with the Newtonian model believe that a constant speed implies no net force, and increasing speed implies a net force. Students whose responses are consistent with an Aristotelian model believe that a constant speed implies a constant net force and an increasing speed implies an increasing net force. These models are consistent with those reported in the literature.[5] When student responses to different questions in a given context are consistent with different models, we say they are in a mixed model state. Fig. 1 shows a vast majority of students give responses consistent with the Aristotelian model in Interview 1 (pre-instruction). In Interview 2 we found that a majority of student responses are consistent with the Newtonian model (see Fig. 1). This observation is expected since Interview 2 was conducted after instruction on Newton's Laws. In Interview 3 we find most students' responses are consistent with the two models . A few students whose responses are consistent with the Newtonian model in Interview 2 are now consistent with Aristotelian model. We also find one more student who is in the mixed model state. Therefore, students' responses vis-à-vis their consistency with a model depends on the context. It is possible that these students' internal knowledge structures include both the Newtonian and Aristotelian frameworks. However, because the contexts in Interview 3 pose some difficulty, students whose previous responses were consistent with the Newtonian model are now triggered to respond consistently with the Aristotelian model. Also, four students whose responses were consistent with the Newtonian model in Interview 2 (after instruction) continue to respond consistently with the Newtonian model in Interview 3.

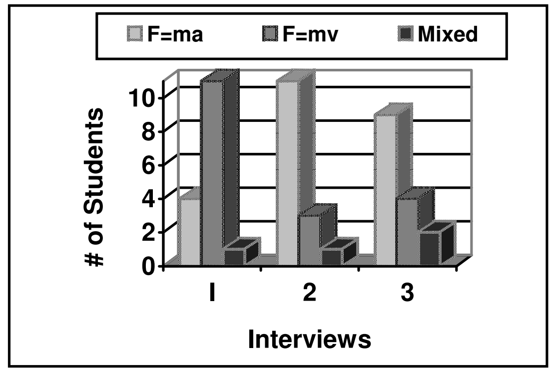

Fig. 1: Results from Interviews 1, 2 and 3 from the first semester.

Table 1 shows how 10 out of the 16 students (who continue into the second semester) progress throughout the interviews. Students S1 and S9 provided responses consistent with the Newtonian model in Interview 2, but not in Interview 3. Responses from all other students were either always consistent with the Newtonian model or tended to become more consistent with the Newtonian model as the semester progressed.

Int	S1	S2	S3	S4	S5	S6	S7	S8	S9	S0
1	A	N	M	A	N	A	A	A	A	A
2	N	N	N	A	N	N	N	N	N	A
3	M	N	N	A	N	N	N	N	A	A

Table 1: Student responses as they progress through the three interviews. 'A' indicates responses consistent with an Aristotelian model in all contexts in a given interview. 'N' indicates responses consistent with a Newtonian model in all contexts in a given interview. 'M' indicates a student in a mixed model state in a given interview.

Instruments: Semester II

In the second semester we adapted questions from the Conceptual Survey in Electricity and Magnetism (CSEM).[6] Ten out of 16 interviewees from the first semester participated in the second semester interviews. Thus we had the opportunity to explore whether these students would continue to respond to questions in electricity and magnetism in ways that were consistent with the models that they had used in mechanics or if they would use different models. In all of our interviews we chose contexts in electricity and magnetism that we believed could elicit reasoning to describe motion, similar to the reasoning used in the mechanics contexts from the previous semester.

In Interview 1 we included two mechanics contexts. These contexts were intended to serve as a baseline since they were similar to other contexts that followed, except that the origin of the force was mechanical (applied and/or gravitational) rather than electrostatic.

The first electrostatic context was based on CSEM question #10:

A positively charged sphere is released from rest in a region with a uniform electric field.

- Describe the force(s) acting on the charged sphere.
- Does the motion of the sphere change if the magnitude of the E field is doubled?
- If the charge of the sphere suddenly doubles, describe its motion
- How would the motion of the sphere change if the direction of the E field were reversed? If it were turned off?

The second context was…

A positively charged sphere moves at a constant speed in a uniform electric field.

- Describe the force(s) acting on the charged sphere.
- How does the motion of the sphere change if the magnitude of the E field is doubled?
- If the charge on the sphere is suddenly doubled, describe its motion.

In Interview 2 we explored the contexts of magnetic fields. The first context in the second interview is based on CSEM question #21:

A positively charged sphere is released from rest in a uniform magnetic field.

- Describe the force(s) on the sphere.
- Describe the motion of the sphere.

Other contexts were as follows:

A positively charged sphere moves at a constant speed in direction from left to right. It enters a region with a uniform magnetic field with horizontal direction from left to right.

Also…

*A sphere with charge +q and mass M moves at a speed V and enters a region with a magnetic field, B. The speed is perpendicular to the magnetic field.*Describe the force(s) acting on the sphere as it enters the magnetic field region…

- if the sphere is twice as fast?
- if the magnitude of B is doubled?
- if the charge is doubled?

In Interview 3 we explored the context of electromagnetic induction. We used contexts similar to those in textbook problems. The first context was:

A loop is pulled out, from left to right, of a region with a uniform magnetic field B, *into the page, at constant speed V.*Describe the force(s) acting on the loop as the loop is pulled.

- If the hand stops pulling, describe the force(s) on the loop and its subsequent motion.The second context was:

A rod of length L moving at constant speed V on two rails in a uniform magnetic field B *region.* B *is out of the page.*Describe the force(s) acting on the rod.

- The magnetic field B is turned off, describe the force(s) in the rod and what happen with its motion.

Results & Discussion: Semester II

Our results for Interview 1 (Fig. 2) show that student responses to questions in the electrical contexts were consistent with the two dominant mental models (Newtonian and Aristotelian). Nine out of the 16 students' responses are consistent with the Newtonian model. A similar trend is observed in Interview 2 that addressed magnetic fields. The number of students whose responses were consistent with the Newtonian model increases.

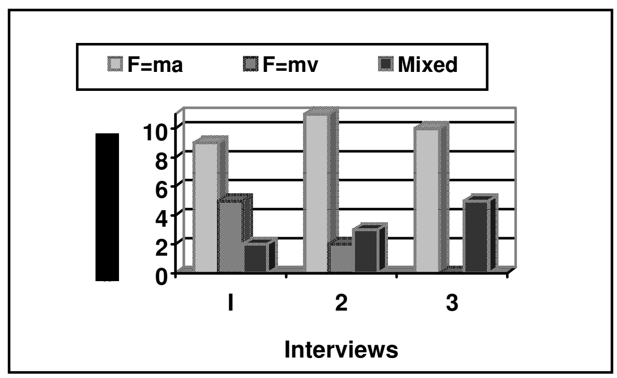

Fig. 2: Results from Interviews 1, 2 and 3 from the second semester. The two principal models found on the first semester remain.

We also found that in the magnetic field contexts, students tended to rely more on equations than before. They appeared to be doing so to make a distinction between an electric and magnetic field while determining the force that influences the motion of the charge. In Interview 3 we again find that most of the student responses are consistent with the Newtonian model and none with the Aristotelian model. Based on their responses in this interview a significant number of students use the mixed model state

Comparing Fig. 2 with Fig. 1 we notice that students' responses are more often consistent with the Newtonian model in the second semester than in the first semester. Though students no longer study mechanics in the second semester they often revisit mechanics ideas in homework problems. Another reason for more Newtonian-like responses in the second semester is because when students are faced with abstract electricity and magnetism contexts they are more likely to base their responses on instruction than on intuitive reasoning as they do in mechanics. Therefore, the context also influences the model used.

Table 2 shows how the 10 returning students progress through the second semester. Responses of students S7 and S10 are consistent with the Newtonian model in Interview 2 but not in Interview 3. They reverted back to a mixed model state in the context of electromagnetic induction. Note that responses from students S2 and S5 are consistently Newtonian-like in all of the six interviews.

Int	S1	S2	S3	S4	S5	S6	S7	S8	S9	S0
1	N	N	N	A	N	N	A	N	N	A
2	N	N	N	A	N	N	N	N	M	N
3	N	N	N	M	N	N	M	N	N	M

Table 2: Student responses as they progress through the three interviews in the second semester. Notation used is identical to Table 1.

Conclusions

We found that students' responses are consistent with two principal mental models (Newtonian and Aristotelian) in Newton's II Law contexts spanning the topical areas of mechanics, electrostatics and magnetism. Some students might use conceptions from both models depending upon the context, i.e. they are in a mixed model state. Students' responses tended to be more Newtonian–like after instruction, but not all of them remain "Newtonian thinkers" through different contexts. In the second semester most students' responses are consistent with the Newtonian model even when the concepts of study are more abstract than on the first semester. Therefore, thinking while responding to physics questions is dependent both on the instruction as well as on the context of the question.

Acknowledgements

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References

1. Johnson-Laird, P.N. "Mental Models: Toward a Cognitive Science of Language, Inference, and Consciousness," *Cognitive Science Series*, Harvard Univ. Press, Cambridge MA., (1983)
2. Bao L., K. Hogg and D. Zollman, "Model Analysis of fine structures of student models: An example with Newton's third law," *Am. J. Phys.* **70** (7) p. 766-778, (2002).
3. Hestenes, D., M. Wells, G. Swackhammer, "Force Concept Inventory,". *The Physics Teacher*, **30**: p. 141-151 (1992).
4. McDermott, Lillian C., "Research on Conceptual Understanding in Mechanics," *Physics Today*, **37** (7), 24 (1984).
5. See Chapter 5, page 181 of: Gabel, Dorothy L. editor, "Handbook of Research on Science Teaching and Learning," Macmillan Publishing Co. (1994).
6. Maloney, David P., Thomas L. O'Kuma, Curtis J. Hieggelke and Alan Van Heuvelen, "Surveying students' conceptual knowledge of electricity and magnetism," *Phys. Educ. Res. Supp, Am. J. Phys.*, **69** (7), S12-S22 (2001).