Third Misconceptions Seminar Proceedings (1993)

Paper Title: Dealing with Students' Preconceptions in Mechanics
Author: Clement, John

Abstract: This paper describes some of the major features of a set of units for dealing with students' preconceptions in mechanics. These units are being published in a curriculum guide book for teachers (Camp and Clement, et al, in press). The book is not a textbook but rather collection of lesson plans that specifically targets some of the most difficult areas in mechanics. The lessons use instructional techniques such as constructing visualizable explanatory models, class discussions of the validity of an analogy between a target problem and an anchoring intuition, and forming a structured chain of intermediate bridging analogies. The experimental group achieved pre-post test gains that were significantly larger than the control group's gains in each area. It is argued that: (1) rational methods using analogy and other non-empirical plausible reasoning processes can play a very important role in science instruction; (2) much more effort than is usually allocated should be focused on helping students to make sense of an analogy; and (3) researchers and curriculum developers should be focusing at least as much attention on students' useful prior knowledge and reasoning processes as they are on students' alternative conceptions.

Keywords: concept formation,educational methods,,cognitive restructuring,cognitive dissonance,learning strategies,constructional design,cognitive structures, misconceptions
General School Subject: physics
Specific School Subject: mechanics
Students: high school

Macintosh File Name: Clement - Mechanics
Release Date: 12-15-1993 B, 11-5-1994 I

Publisher: Misconceptions Trust
Publisher Location: Ithaca, NY
Volume Name: The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics
Publication Year: 1993
Conference Date: August 1-4, 1993
Contact Information (correct as of 12-23-2010):
Web: www.mlrg.org
Email: info@mlrg.org

A Correct Reference Format: Author, Paper Title in The Proceedings of the Third International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Misconceptions Trust: Ithaca, NY (1993).

Note Bene: This paper is part of a collection that pioneered the electronic distribution of conference proceedings. Academic livelihood depends upon each person extending integrity beyond self-interest. If you pass this paper on to a colleague, please make sure you pass it on intact. A great deal of effort has been invested in bringing you this proceedings, on the part of the many authors and conference organizers. The original publication of this proceedings was supported by a grant from the National Science Foundation, and the transformation of this collection into a modern format was supported by the Novak-Golton Fund, which is administered by the Department of Education at Cornell University. If you have found this collection to be of value in your work, consider supporting our ability to support you by purchasing a subscription to the collection or joining the Meaningful Learning Research Group.

----- -----

DEALING WITH STUDENTS' PRECONCEPTIONS IN MECHANICS

John Clement
Scientific Reasoning Research Institute
University of Massachusetts
USA

INTRODUCTION

<u>Overview</u>

This paper describes some of the major features of a set of units for dealing with students' preconceptions in mechanics. These units are being published in a curriculum guide book for teachers (Camp and Clement, et al, in press). The book is not a textbook but rather collection of lesson plans that specifically targets some of the most difficult areas in mechanics. The lessons use instructional techniques such as constructing visualizable explanatory models, class discussions of the validity of an analogy between a target problem and an anchoring intuition, and forming a structured chain of intermediate bridging analogies. The experimental group achieved pre-post test gains that were significantly larger than the control group's gains in each area. It is argued that: (1) rational methods using analogy and other non-empirical plausible reasoning processes can play a very important role in science instruction; (2) much more effort than is usually allocated should be focused on helping students to make sense of an analogy; and (3) researchers and curriculum developers should be focusing at least as much attention on students' useful prior knowledge and reasoning processes as they are on students' alternative conceptions.

<u>Persistent Preconceptions</u>

Research reported at these meetings has shown that physics students exhibit qualitative preconceptions-- ideas that they bring to class with them prior to instruction in physics. It has also shown that certain preconceptions conflict with the physicist's point of view in many circumstances. It has also shown that some of these conflicting preconceptions are quite persistent and seem to resist change when using normal instructional techniques. The lessons to be described here are aimed specifically at some of these particularly troublesome areas in mechanics and use special techniques for dealing with them. I will first give an overview of this set of lessons and then describe an experiment in which they were compared with control classes, using a test designed to detect persistent preconceptions in mechanics.

DESCRIPTION OF LESSON UNITS

Lesson Development

The lessons are grouped together in the following units:

1. Normal Forces From Static Objects
2. Relative Motion
3. Frictional Forces
4. Tension
5. Gravity I
6. Inertia I
7. Gravity II
8. Inertia II
9. Newton's Third Law in Dynamics

The lessons are designed to supplement any course that includes mechanics. They were created by a team of researchers and teachers who have worked together for seven years to design, test, and improve the lessons. They were tested in classes for both standard, upper, and lower level high school physics students, and extensively revised on the basis of classroom observations.

General Goals

Several general goals guided the design of these lessons:

Content Goals:

- To help students understand fundamental ideas where there are common preconceptions differing from the physicist's view

- To help students build concepts that make sense to them by starting from useful intuitions

- To help students construct explanatory models-- the causal mechanisms that give rise to physical effects. These embody important knowledge that goes beyond rules describing patterns in observations

- To make connections to other physics concepts and to familiar everyday phenomena

Process Goals:
To encourage students to:

• Actively participate in intellectual discussions

• Decide whether ideas make sense to them and work to make ideas make sense

• Generate analogies and explanatory models

• Criticize and evaluate explanatory models and analogies by formulating arguments for and against them

• Extend concepts to new applications

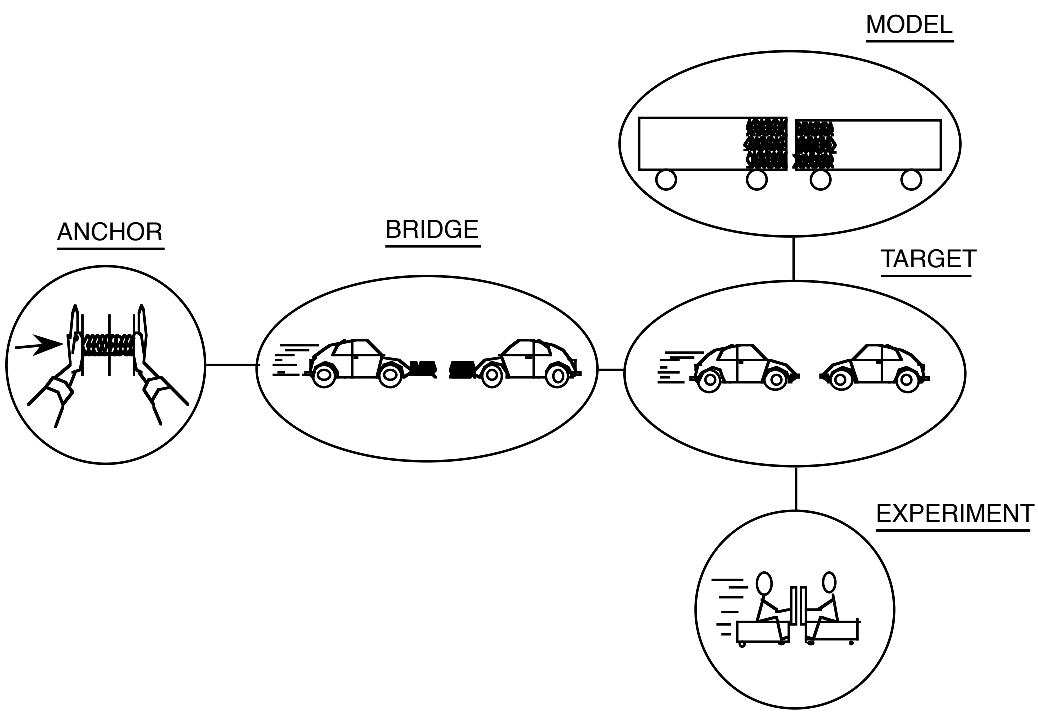

Figure 1

Example of a Lesson: Newton's Third Law in Dynamics

An example of one of the lessons is the Newton's third law in dynamics lesson illustrated in Fig. 1. This figure shows several concrete situations that provide "thought examples" for the students to discuss. The students first discuss and "vote on" a target problem (one that draws out a misconception in many students) of a moving car colliding with a stationary car of the same mass, as shown in Figure 1. The question is whether one car exerts a greater force on the other, or whether the forces are equal. Students also fill in a scale on a voting sheet indicating "how much sense" their answer makes to them. Most students respond that the moving car exerts the greater force, contrary to the physicist view that there will be equal and opposite forces exerted in the interaction.

Next, students are asked about the moving hand on the springs situation in Figure 1. Here two springs with a board between them are compressed by moving the left hand only. At this stage in their learning, we have found that most students will agree that the springs will compress the same amount and will exert an equal force on each hand while the left hand is moving. This is a useful starting point for instruction since it draws out an intuition from students that is largely in agreement with the physicist. For this reason it is called an "anchoring example" that draws out an anchoring intuition in the student.

A strategy that fails. A plausible instructional strategy would be to present the hands-compressing-springs anchor and the colliding cars problem to students and ask them if they are not indeed analogous. Unfortunately this simple strategy does not often work. Instead, students typically say that the cars are not like the spring- to them the moving car's speed gives it so much power that it *must* exert a larger force--so the ends of the spring can exert equal forces while the cars cannot. Thus there is a need for an additional effort to help students see how the analogy between the springs and the cars can be valid.

Bridging analogies. Figure 1 shows an intermediate case used to help students determine that the analogy between the "hand on the spring" anchor and the targeted colliding cars case is valid. The strategy of finding an intermediate third case that shares features with both the original case and the analogous case is termed a bridging analogy. Here, the idea of two cars with heavy springs attached to them (case B) shares some features of the original colliding cars problem (case C) and some features of the hands on the springs (case A). The subject may then be convinced that A is analogous to B and that B is analogous to C with respect to the same important features, and thereby be convinced that A is analogous to C. Such bridges are not deductive arguments, but experts have been observed to use them as a powerful form of plausible reasoning (Clement, 1986; 1988). Presumably, this method works because it is easier to comprehend a "close" analogy than a "distant" one; the bridge divides the analogy into two smaller steps that are easier to comprehend than one large step. Students were asked to discuss how the bridging case might be similar to or different from the anchor and target examples.

A microscopic explanatory model. The students were then asked to think of the surface of the cars as containing spring-like bonds between their atoms (a microscopic model). This is the first time, after considerable discussion, that the teacher is allowed (by implication) to reveal his or her position on the target question.

Demonstration. At the end of this lesson an experiment was done where a student riding on a projection cart collided with another student on a stationary cart. Bathroom scales held by each student out in front of the carts received the impact of the collision. Students predicted whether one reading would be consistently larger. These give very rough measurements, but they are accurate enough over several trials to provide conflict for students who hold that the forces will be quite different. The second lesson extended this idea to unequal masses using similar questions.

General Strategies

A number of strategies used in the lesson just described were used in many other lessons, as follows.

Discussion. The lessons were designed to encourage open discussion, where students were encouraged to think about and explain what they believe about a physical situation. The teachers stayed neutral in these discussions until all points of view had been heard.

Voting. At key points, the lessons call for the students to vote on their belief about the target problem and other bridging examples. These give the teacher valuable information on the students' conceptions and how they change during the lesson. Along with the vote, the voting sheet asks students to report "how much sense" each answer makes to them.

Anchoring analogies, bridging, and model construction. Many of the lessons use the bridging analogies strategy and have been described in Clement, et al.., (1987) and Clement (in press). Many also develop a visualizable model of the mechanism(s) providing forces in the target problem.

Empirical demonstrations. Empirical demonstrations were used occasionally to disequilibrate students' alternative conceptions or to support an aspect of the analogue model such as the presence of deformation in rigid objects.

Other strategies. A number of the lessons use other strategies as well, such as: selecting examples to encourage concept differentiation, use of intermediate concepts as stepping stones to the physicist's concepts, exercises in verbal explanation, splitting units into parts that could be revisited, and separate discussion of natural subdomains (such as gravity on earth and gravity between planets) that are naturally thought about in separate ways by students but not by physicists (Brown and Clement, 1992).

EXPERIMENTAL STUDY

The lesson units described above were evaluated by giving identical pre and post tests to experimental and control classes in high school physics. Experimental students were given two one period lessons on normal forces, one on friction, three on relative motion, one on tension, three on gravity, four on inertia, and two on the dynamic third law. (The latter three units contain several more lessons in the current final version.) Discussions of homework and quiz questions took up to one additional period in each of the units. The lessons were introduced at the different points where they fit into the students' study of mechanics during the year. Control classes studied their normal curriculum.

Data Collection

The test instrument consisted of questions designed to detect common alternative conceptions in each of the three areas and contained both near and far transfer questions. Questions from five of the units are described in Brown and Clement (1987), and Brown and Clement, (1992). Identical pre and post tests were given about six months apart: the retention periods measured by the post tests were two months or more for all lessons. Teachers were blind to the problems on the tests.

Research Results

Table 1 shows the results on the dynamic third law unit. The experimental group achieved significantly larger pre-post test gains than the control group. This was also true in each of the seven lesson areas. The difference between the gains was on the order of one standard deviation in six of the seven areas.

Dynamic Third Law Gains

(Points Possible = 6)	Pretest	Posttest	Gain
Control	1.24 (20.7%)	2.11 (35.2%)	0.87 (14.5%)
(S.D.)	(1.15)	(1.50)	(1.29)
Experimental	1.56 (26.0%)	4.21 (70.2%)	2.66 (44.3%)
(S.D.)	(1.43)	(1.58)	(1.85)

Experimental group showed larger gain ($t = 6.54$, two-tailed, $p < .0001$)

Table 1

Taken together, the lessons produced an average gain difference of 27.5% or about one and one third standard deviations ($t= 8.41$, two tailed, $p < .0001$). Thus we were encouraged that the increased time and effort spent on these lessons is able to produce large gain differences on instruments designed to detect persistent preconceptions.

Null results in early versions. Early versions of the gravity and inertia units produced zero gain differences over controls in their first year of classroom trials, even though experimental groups spent longer on these topics than the control groups. This was very disappointing after a large curriculum development effort during the summer with the team of teachers and researchers. This leads us to believe that increased time and care spent on a topic may be a necessary but not sufficient factor in producing larger gains where there are persistent preconceptions.

Teacher experience. As much care as possible was given to picking control teachers who were as competent as the experimental teachers. (One of the control teachers was voted best physics teacher in the state in a previous year. The other control teacher had been selected to be involved as an experimental instructor in another NSF project in previous years.) Both were quite experienced and had excellent reputations. Two of the three experimental teachers, on the other hand, had taught physics for 2 years or less, having previously taught biology in one case and junior high science in the other.

Qualitative Observations

Qualitative observations from video tapes of these classes indicated that: (1) some students changed their minds toward the physicist's view during each major section of the lesson, e.g., after the anchor, bridge, model, and demonstration sections, leading us to hypothesize that each technique was helpful to some subset of students. (Brown [1987] reports evidence from tutoring studies which provides further support for this hypothesis); and (2) students were observed generating several types of interesting arguments during discussion, such as: generation of analogies and extreme cases of their own; explanations via a microscopic model; giving a concrete example of a principle; arguments by contradiction from lack of a causal effect; generation of new scientific questions related to the lesson; and even spontaneous generation of bridging analogies. This last observation gives us reason to believe that even though the lessons were designed primarily with content understanding goals in mind, some process goals were also being achieved as an important outcome.

DISCUSSION

Research Needed On Anchors

Potential anchoring examples can be listed by skilled teachers, but they require empirical confirmation (Clement, Brown, and Zietsman, 1989). For example, our team confidently predicted that hitting a wall with one's fist would be an excellent anchoring example for the idea that a static object can exert a force. Surprisingly however, only 41% of pre-physics students tested agreed that the wall would exert a force on one's hand. Thus empirical studies are needed to find good anchors -- not just any concrete example that makes sense to the teacher will work. This leads one to believe that researchers and curriculum developers should be focusing at least as much attention on students' useful prior knowledge and reasoning processes as they are on students' alternative conceptions.

Constructivist Nature Of The Approach

It might be argued that since the lessons contain carefully selected thought examples they must be primarily didactic in nature. Although the teachers introduce target and anchoring examples into the discussion, they do *not* reveal their opinion on whether the anchor is analogous to the target problem. Thus *the students are actively engaged for extended periods in evaluating whether the examples are analogous or not and in finding the best way to view the target situation,* and this is encouraged further by having them vote on issues periodically during the discussion. Thus the lessons emphasize interaction with the prior knowledge and reasoning abilities of the students as a form of guided constructivism.

Plausible Reasoning Vs. Formal Proof Processes In Instruction

Polya (1954) identified a set of important plausible reasoning strategies in mathematics. Bridging analogies are a form of plausible reasoning process that has only recently been documented in experts solving scientific problems (Clement, 1986, 1989). As in the case of experts, the bridging cases used here appear to work with knowledge representations that are qualitative physical intuition schemas, not at a level that uses formal notations. Bridging appears to be an important tool for stretching the domain of applicability of an anchoring intuition to a new situation, i.e., for making the intuition more general and powerful. Analogies and bridging may therefore be important plausible reasoning strategies for developing and refining physical intuitions. It may be that such selected plausible reasoning processes are more powerful than logical proof processes for the development of qualitative ideas that make sense to students.

Demonstrations And Laboratories Not More Central Than Other Methods

A demonstration is included at the end of most of the present lessons for other purposes, but none were built around a demonstration that provided conclusive evidence for the physicist's model. Instead, the lessons focused more energy on the development of analogy relations and conceptual understanding than is ordinarily done, and rational arguments were fostered at least as much or more than empirical ones. Our group has also obtained significant gain differences in tutoring interviews on static normal forces for twelfth graders (Brown, 1992) and on levers for seventh graders (Zietsman, 1990) without using any demonstrations or laboratories. Thus it appears to be possible to affect students' alternative conceptions in some cases without relying on laboratories or demonstrations as a dominant method. Our current hypothesis is that demonstrations and laboratories can and should play a powerful role in instruction but that they are only a piece of what is needed. It is interactions between empirical and rational processes that are sought. Discussions of rational thought-examples not only tap important anchoring conceptions, they may raise questions and conflicts that prepare students to see the significance of an empirical demonstration and to think about it and discuss it actively rather than memorizing the result. Thus rational methods using analogy and other plausible reasoning processes that are neither proof-based nor directly empirical can play a very important role in learning science.

Notes

* I would like to acknowledge the invaluable assistance of a number of people on the lesson authoring and research teams without whom this paper could not have been written, namely: David Brown, Charles Camp, Kimberly Gonzales, John Kudukey, James Minstrell, Jim Monaghan, Klaus Schultz, Melvin Steinberg, and Valerie Veneman.

REFERENCES

Brown, D. (1987). Using analogies and examples to help students overcome misconceptions in physics: A comparison of two teaching strategies. Unpublished doctoral dissertation, University of Massachusetts.

Brown, D., & Clement, J. (1987). Misconceptions concerning Newton's law of action and reaction. Proceedings of the Second International Seminar on Misconceptions and Educational Strategies in Science and Mathematics. Ithaca, NY: Cornell University.

Brown, D. & Clement, J. (1992). Classroom teaching experiments in mechanics. In R. Duit, F. Goldberg & H. Niedderer (Eds.) Research in physics learning - theoretical issues and empirical studies. San Diego, CA: San Diego State University.

Camp, C., Clement, J., Brown, D., Gonzalez, K., Kudukey, J., Minstrell, J., Schultz, K., Steinberg, M., Veneman, V., & Zietsman, A. (in press). Preconceptions in mechanics: Lessons designed to deal with student's conceptual difficulties. Dubuque: Kendall-Hunt.

Clement, J. (1986). Methods for evaluating the validity of hypothesized analogies. Proceedings of the Eighth Annual Meeting of the Cognitive Science Society. Hillsdale, NJ: Lawrence Erlbaum Associates.

Clement, J. (1988). Observed methods for generating analogies in scientific problem solving. Cognitive Science, 12, 563-586.

Clement, J. (1989). Learning via model construction and criticism: Protocol evidence on sources of creativity in science. In J. Glover, R. Ronning, and C. Reynolds (Eds.), Handbook of creativity: Assessment, theory and research. NY: Plenum.

Clement, J. (in press). Using bridging analogies and anchoring intuitions to deal with students' preconceptions in physics. Journal of Research in Science Teaching.

Clement, J., Brown, D. & Zietsman, A. (1989). Not all preconceptions are misconceptions: Finding "anchoring conceptions" for grounding instruction on students' intuitions. International Journal of Science Education, 11, 554-565.

Clement, J., Brown, D. Camp, C., Kudukey, J., Minstrell, J., Schultz, K., Steinberg, M., Veneman, V. (1987), Overcoming students' misconceptions in physics: The role of anchoring intuitions and analogical validity, in Novak, Joseph D., Proceedings of The Second International Seminar on Misconceptions and Educational Strategies in Science and Mathematics, Vol. 3. Ithica, NY: Cornell University.

Polya, G. (1954). Mathematics and plausible reasoning vol. 1: Induction and analogy in mathematics, 155. Princeton, NJ: Princeton University Press.

Zietsman, A. (1990). Case studies of cycles in developing a physics lesson. Unpublished doctoral dissertation, University of Massachusetts.