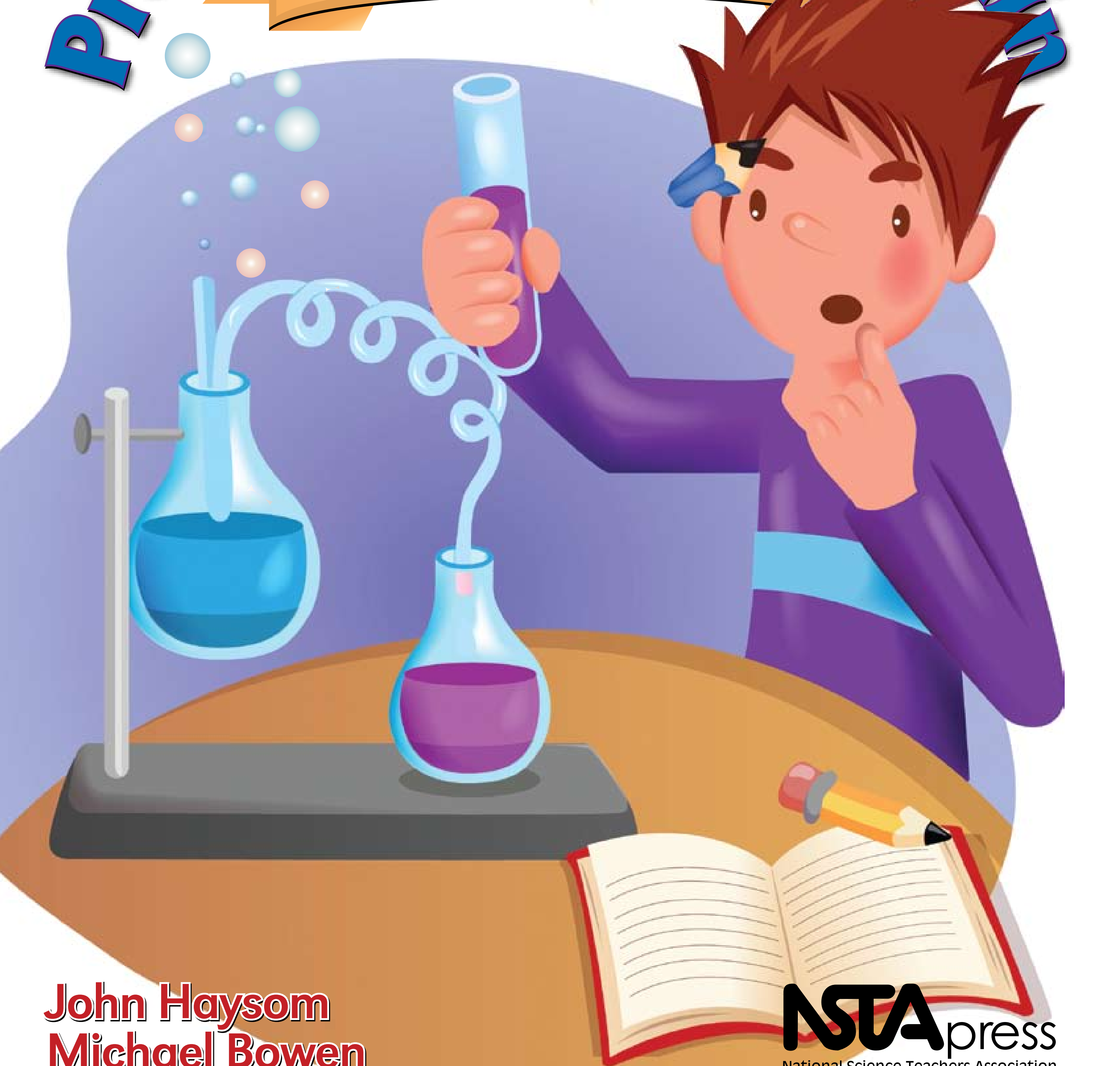
Predict, Observe, Explain

Activities Enhancing Scientific Understanding



John Haysom
Michael Bowen

NSTApress
National Science Teachers Association

Predict, Observe, Explain

Activities Enhancing Scientific Understanding

Predict, Observe, Explain

Activities Enhancing Scientific Understanding

John Haysom
Michael Bowen

NSTA press
National Science Teachers Association
Arlington, Virginia

NSTApress®
National Science Teachers Association

Claire Reinburg, Director
Jennifer Horak, Managing Editor
Andrew Cooke, Senior Editor
Judy Cusick, Senior Editor
Wendy Rubin, Associate Editor
Amy America, Book Acquisitions Coordinator

ART AND DESIGN
Will Thomas Jr., Director
Cover illustration: Lushpix Illustration/Unlisted Images, Inc.
Interior illustrations: Tim French

PRINTING AND PRODUCTION
Catherine Lorrain, Director

NATIONAL SCIENCE TEACHERS ASSOCIATION
Francis Q. Eberle, PhD, Executive Director
David Beacom, Publisher

13 12 11 10 4 3 2 1

Library of Congress Cataloging-in-Publication Data
Haysom, John, 1938-
Predict, observe, explain : activities enhancing scientific understanding / by John Haysom and Michael Bowen.
p. cm.
Includes bibliographical references and index.
ISBN 978-1-935155-23-2
1. Science--Study and teaching (Middle school)--Activity programs. I. Bowen, Michael, 1962- II. Title.
Q181.H37555 2010
507.1'2--dc22
2010027459

eISBN 978-1-936137-59-6

Table of Contents

The Story of a Curriculum Development Project

Acknowledgments

This is a brief story of a curriculum project designed to produce learning materials that enhance students' understanding of important scientific concepts. It is not the story of a traditional curriculum project but, rather, of a project designed to involve practicing teachers in a meaningful way. Many teachers contributed in different ways, and this story is an expression of thanks for the efforts they made at different stages of the project. It also acknowledges the help received from science teacher educators in Canada, the United States, Australia, New Zealand, and the United Kingdom.

The story begins at a conference organized by Gaalen Erickson at the University of British Columbia (UBC). It was here that I learned about the power of Predict, Observe, Explain sequences (POEs) from two teacher-researchers, Jim Minstrell and Ian Mitchell. These people unknowingly planted the seed for this project.

Upon returning from my sabbatical at UBC, I made a request to Saint Mary's University for support. Over the course of the next three years, the university provided graduate assistantships to Clayton Coe, Judy Reynolds, Bob Dawson, Nevin Jackson, and Norma MacSween, all practicing teachers who were studying for their master's degrees. I also received invaluable help in the design and preparation of the trial materials from Sue Kent. On reflection, it is easy to recognize that this sort of support is crucial; without it, the project struggled to keep going.

The first task in Year 1 involved the design of sample learning sequences. This began with an extensive and comprehensive search of the research literature on children's scientific ideas. It was carried out by Clayton Coe with the assistance of librarian Doug Vaisey. In many instances, the research procedures used to elicit students' ideas stimulated the design of POE sequences. In addition, we scoured the products of other curriculum projects, especially SciencePlus by the Atlantic Science Curriculum Project, for ideas for activities that would lend themselves to being presented in the form of POEs. In subsequent years, many others contributed their ideas for learning sequences, notably Dick Gunstone and the Monash Children's Science Group.

Even though the learning sequences we had designed were far from perfect, we launched the field testing and evaluation of the materials at the end of the first year. We invited teachers to select a topic they would be teaching and return their evaluation of each sequence they used. The evaluation form was a simple one: We asked the teachers to rate the sequence on a five-point scale, provide their reasons for the rating, and note any problems they encountered when using the sequence, along with suggestions for making improvements. In addition, we had the hunch that the teachers themselves would benefit from using the POEs. Judy and Clayton examined their responses, and many reflected on the way in which they taught science. Here are some sample responses.

> ***POEs have given me more insight into the misconceptions students bring with them into a science class.***
>
> ***They have shown me that it is important for all students to reflect on their understanding of concepts and to verbalize it before and after the POE experience.***

Their findings were presented at a meeting of the Canadian Society for the Study of Education.

In the second year, Bob Dawson and Nevin Jackson focused on field testing and evaluation. Following a number of presentations at inservice meetings, which received enthusiastic responses, we invited the teachers to select a booklet of POEs on a topic they would be teaching. In return they undertook to send their evaluations of each POE they used, together with the students' scripts. However, by the end of the year, the return had been patchy, especially regarding the students' scripts. We attributed this to the demands we were making on the teachers' time, especially regarding the photocopying of the student worksheets.

As a consequence, in Year 3, we made contracts with a number of committed teachers and provided workbooks for all their students. Chuck McMillan, Bill Reid, and Frances Wallace undertook the bulk of the testing. This worked very well, even though we were unable to test all the POEs and we finished up with a pile of workbooks about two meters high. Norma MacSween began analyzing these. This project—coupled with revising the materials, checking the literature, and preparing for publication—proved to be an enormous task.

The writing of this book was brought to fruition when I renewed a long-standing professional relationship and brought my former student Michael Bowen on board to work with me in finalizing the POEs, organizing the writing, sourcing reference literature in the teaching guides, and honing the final text and images.

In addition to the people mentioned above, I would like to acknowledge the invaluable efforts of all of those who have assisted in this project. They have all helped bring together curriculum development, classroom teaching, and education research in a way that we hope will make an important contribution to science education.

—John Haysom

Using POE Sequences

POE sequences provide an important way to enhance your students' understanding of important scientific ideas. We believe that POE sequences are an important tool in every science teacher's repertoire. If you are teaching a traditional curriculum, one based on a textbook, the sequences can enliven the enrichment you provide. If you are teaching an activity-based curriculum, they can help provide a firm basis for understanding. POEs are based on a sound theoretical foundation that has been researched extensively.

Children live in a world of sense impressions. They see, hear, smell, touch, and taste. From infancy they spontaneously make sense of the world in which they live. They form concepts and try to link one concept with another to explain the world around them. For example, they might come to think that matter disappears when substances dissolve or burn, or that plants take in food through their roots, or that heavy objects such as stones or nails sink, or that heavy objects fall more quickly than lighter ones. They find such ideas useful in their lives. The idea that children—or all of us, for that matter—construct such understandings of the world is fundamental to the constructivist view of learning.

Scientists also try to make sense of the natural world of sense perceptions. This is their collective mission. They do this deliberately and carefully. They extend our sensory world by using instruments to measure mass, length, and time more accurately. They use instruments to measure the large and the small, the hot and the cold, the soft and the loud, and so on, to enhance our sensitivity. They expand the natural world by carrying out experiments, enabling them to observe phenomena that do not occur naturally. They formulate concepts such as density and gravitational force and arrive at powerful generalizations, such as that an object floats when its density is less than that of the liquid in which it is immersed, or the acceleration of all falling objects is the same in a vacuum.

There are thus two types of interpretations of the world in which we live: everyday, commonsense interpretations and those of the community of scientists. It is part of a science teacher's job to help each student build on everyday, commonsense interpretations so that the student can adopt and internalize scientists' interpretations. This can be a very challenging task, especially when the scientific interpretation is at odds with students' interpretations. For example, some students believe that electricity gets used up as it goes around a circuit, or that vacuums suck. These ideas have worked well for the students concerned. So why should they change their ideas now?

How can the science teacher respond to this challenge? A variety of teaching strategies have been developed to complement the constructivist view of learning. As you would expect, they have many features in common. The POE sequences we have developed embrace many of these features. They are included in the suggestions for using the POEs that follow. As you read about the steps in the sequence, you might find it useful to refer to one or two POEs to provide examples.

Step 1: Orientation and Motivation

The POE usually begins by drawing on the students' past experiences or previous understanding and raises a challenging question that can be addressed through the experiment that follows. A few minutes of full-class discussion will provide the students with the opportunity to reflect on their past experiences and understanding.

Step 2: Introducing the Experiment

Introduce the experiment. Linking it to the previous discussion will help make it meaningful.

Step 3: Prediction: The Elicitation of Students' Ideas

Before doing the experiment, ask the students to write down on the worksheet what they predict will happen, along with the reasons for their predictions. This exercise is valuable for both the students and the teacher. Making their reasons explicit helps the students become more aware of their own thinking. It also provides the teacher with useful insights and an opportunity to plan ahead. Hence, while students are writing, you might stroll around so as to prepare yourself for the discussion that will follow.

Step 4: Discussing Their Predictions

This is a two-stage process. First, ask your students to share their predictions in full-class discussion, using a chalkboard or SMART Board to highlight the range of predictions and reasons for them. This needs to be handled with sensitivity on account of some students' feeling anxious about seeming "wrong." Hence, you will need to be supportive and encourage as many students as possible to express their viewpoints. There are no poor ideas! All ideas are valued because they represent our best efforts to make sense of the world. You might explain that making our predictions explicit helps us learn.

After this has been done, you might invite the class to discuss which predictions and reasons they now think are best. When students reconsider their reasons, some may begin to change their minds and reconstruct their thinking. Immediately prior to the experiment, it's often fun and illuminating to have a straw vote about the outcome.

Step 5: Observation

Most of the experiments in this book are designed to be done as demonstrations, although some make good student explorations. If you demonstrate the experiment, invite the students to help out whenever appropriate. Ask them to write down their observations.

Step 6: Explanation

Students often reshape their ideas through talking and writing. We have frequently found that it's useful for students to discuss their explanations of what they observed with a neighbor or in a small group before formulating a written explanation. They seem to find this action reassuring. After they have done this, collect a sample and invite a full-class discussion of these as appropriate.

Step 7: Providing the Scientific Explanation

Introduce the scientific explanation by saying, "This is what scientists currently think," rather than, "This is the right explanation." Many teachers choose to ask their students to write the explanation in their notebooks or on the back of their activity record sheets. The students might then be invited to compare their explanations with those of scientists, looking for similarities and differences (another opportunity for them to reconstruct their ideas).

Step 8: Follow-Up

Researchers have found that students' ideas often are resistant to change and there is no guarantee that a POE will do the trick, even though it might provide a valuable beginning. This also was evident in the field testing, when student explanations before and after the experiment were compared. Hence, in some POEs, we have included a follow-up at the end. This often is designed to help the students reconsider or apply the scientific ideas they have just encountered and begin to appreciate how useful they are for explaining natural phenomena.

So many steps may seem to make POEs complex and unmanageable, but this isn't the case in practice. The underlying pedagogy resonates with the beliefs held by most teachers, and after a little experience you will probably find the procedure becomes routine for both you and your students. This is liberating and will enable you to focus your attention on facilitating learning by responding to your students. Incidentally, many teachers have found that they can complete Steps 1 through 7 in a 40-minute period. Sometimes they take a break after Step 5: Observation, and set the next step for homework.

A major strength of POEs is that they can continuously provide you with insights into your students' thinking: Steps 1 through 4 probe your students' initial conceptions, Steps 6 and 7 enable you to monitor your students' efforts to reconstruct their thinking, and Step 8 provides you with feedback on your students' progress. POEs thus can offer you "authentic responses" from your students, provided that judgment and assessment do not come into play. It's important, therefore, to encourage your students to share their thinking, which for the time being may or may not be scientifically acceptable, and to value their responses. In this way, it becomes possible for you to adjust the pace of your teaching and to plan for subsequent instruction, thus optimizing your effectiveness.

The Teacher's Notes

Alongside each POE, you will find the scientific explanation; students' explanations: field experience; students' explanations: research findings; and apparatus and materials.

Scientific Explanations

We have tried to express these in a student-friendly form, one you might choose to use in Step 7.

Students' Explanations: Field Experience

These might well be worth reading before you use the POE because they can help you anticipate what your students might say. Even though your class of students will be unique, it could well be that they will have similar ideas to those we have found. On account of the way in which the field testing was conducted, it was not possible to provide these students' explanations for all of the POEs. In these cases, we hope you might make time to analyze some of your own students' scripts.

Students' Explanations: Research Findings

The research findings similarly provide you with an idea about the responses that your students might give, and you might find it interesting to check these out not only before but also after using a POE. When you do this, you will be locating your personal experience alongside the body of knowledge about teaching, and this can be professionally enriching.

In most cases, we expect that you will find it sufficient to simply refer to these summaries. However, some teachers, perhaps those engaged in further study, might find it worthwhile to go into greater depth. As was mentioned before, this area has been extensively researched, and literally hundreds of papers have focused on children's ideas. *Making Sense of Secondary Science* (Driver et al. 1994) is a wonderful resource that summarizes the findings through the date of publication. These days, the research literature is much more accessible, and fortunately this has removed much of its esoteric nature. Accessibility of the literature has been made possible by the arrival of Google Scholar. If you have a reference, you may view a summary or abstract of the article simply by filling in a few key words on the Advanced Scholar Search page. Sometimes the whole article is available, but if it is not and the article looks promising, many libraries, especially university libraries, will be able to help you access it. (A comprehensive bibliography of students' and teachers' conceptions and science education up to 2009 by Reinders Duit is available online: *www.ipn.uni-kiel.de/aktuell/stcse/stcse.html*.)

During the field testing, we were intrigued to find many similarities between our experience and these research findings, and it was illuminating to compare the two. Because many of our POEs and elicitation procedures are original, we have incidentally added to these findings. Moreover, we hope that in the future some teachers will take time to analyze their students' scripts, especially where we weren't able to do so, and thus add to this body of work by becoming researchers themselves.

Apparatus and Materials

Teachers often have difficulty acquiring and storing the necessary apparatus. With this in mind, we have tried to keep the requirements simple and have recommended the use of everyday items wherever possible. We would like to offer these two ideas, which may help teachers overcome the problem:

1. You might organize a curriculum night for parents featuring POEs. We are confident they would enjoy participating in a simulation of one or two sequences themselves. At the end, you could solicit their help in acquiring the materials you need, dividing up the apparatus and materials lists between them.
2. We have found that shoe boxes, fish trays, and other similar containers are useful for storing the items needed for most POEs. They can be labeled and kept on a shelf, ready to use at a moment's notice.

Finally, a few comments about your use of the student activity sheets. It is our intention that teachers who own this book should be free to copy the activity sheets for their own students' classroom use. To facilitate this, the publishers selected a binding that makes it possible to easily open the book and keep it flat. However, we gather that in some schools and districts there are strict policies about making limited photocopies. In such cases, many teachers have reported that they copy the student POE pages onto overhead transparencies or PowerPoint slides and have students answer the questions in their notebooks. To us, this would not be as effective for learning; we carefully considered the layout and space allotted for writing to enhance student engagement and provide students with a record of the activity. Nevertheless, it certainly helps overcome the problem.

Reference

Driver, R., A. Squires, P. Rushworth, and V. Wood-Robinson. 1994. *Making sense of secondary science*. London and New York: Routledge.

Safety in the Classroom Practices

Although most of the experiments are designed to be done as demonstrations, some make very good student explorations. It is important to set a good example and to remind students of the pertinent safety practices when they do perform an experiment.

1. Always review Material Safety Data Sheets (MSDS) with students relative to safety precautions in working with hazardous materials.
2. Remind students to only view or observe animals and not to touch them unless instructed to do so by the teacher.
3. Use caution when working with sharp objects such as scissors, razor blades, electrical wire ends, knives, or glass slides. These items may cut or puncture skin.
4. Wear protective gloves and aprons (vinyl) when handling animals or working with hazardous chemicals.
5. Wear indirectly vented chemical splash goggles when working with liquids such as hazardous chemicals. When working with solids such as soil, metersticks, glassware, and so on, safety glasses or goggles can be worn.
6. Always wear closed-toe shoes or sneakers in lieu of sandals or flip-flops.
7. Do not eat or drink anything when working in the classroom or laboratory.
8. Wash hands with soap and water after doing the activities dealing with hazardous chemicals, soil, biologicals (animals, plants, etc.), or other materials.
9. Use caution when working with clay. Dry or powdered clay contains a hazardous substance called silica. Only work with and clean up clay when wet.
10. When twirling objects around the body on a cord or string, make sure fragile materials and other occupants are out of the object's path.
11. Use only non-mercury-type thermometers or electronic temperature sensors.
12. When heating or burning materials or creating flammable vapors, make sure the ventilation system can accommodate the hazard. Otherwise, use a fume hood.
13. Select only pesticide-free soil—commercially available for plant labs and activities.
14. Many seeds have been exposed to pesticides and fungicides. Wear gloves and wash hands with soap and water after an activity involving seeds.
15. Never use spirit or alcohol burners or propane torches as heat sources. They are too dangerous.
16. Use caution when working with insects. Some students are allergic to certain insects. Some insects carry harmful bacteria, viruses, and so on. Use only biological supply house insects and wear personal protective equipment, including gloves.
17. Immediately wipe up any liquid spills on the floor—they are slip-and-fall hazards.

About the Authors

After completing his doctorate in chemistry at Cambridge University, **John Haysom** taught science in various schools before becoming a member of the faculties of education at five universities: Oxford University, Reading University (United Kingdom), University of the West Indies, Saint Mary's University (Canada), and Mount Saint Vincent University (Canada).

John has gained an international reputation as a teacher educator and curriculum developer. In the United Kingdom, he was coordinator of the groundbreaking Science Teacher Education Project, funded by the Nuffield Foundation. This was probably the first teacher education curriculum project in the world and was adapted for use in Australia, Canada, Israel, and other countries. At the University of the West Indies, he was responsible for the design and implementation of an innovative, theme-based inservice B.Ed. curriculum. As a professor of education at Saint Mary's University, he initiated and helped lead the Atlantic Science Curriculum Project's SciencePlus textbook series. This curriculum was highly rated and became widely adopted in the United States. He has acted as a science curriculum consultant to the government of Trinidad and Tobago and to a number of projects in the United States.

He is the author of many books for teacher educators, teachers, and schoolchildren, as well as academic papers in curriculum design, evaluation and implementation, and teacher education.

Michael Bowen completed his doctorate at the University of Victoria. After studying the research practices of field biologists, he developed a curriculum for middle school students. This was tested with grade 6 and 7 students in the classroom. Following a postdoctoral fellowship in the sociology department at Trent University, he became a member of the faculties of education at three universities: Lakehead University, the University of New Brunswick, and Mount Saint Vincent University (where he is now an associate professor).

Michael's ongoing research has many facets, including studying student learning from participation in science fairs, the development of competency with science inquiry practices in student teachers, and the creation of online communities of learners where participants conduct and share research projects in a science-project-specific social networking site. His research has been presented at national and international conferences in Canada, the United States, and Europe and has been published in journals in jurisdictions throughout the world. The work he is most proud of is that which has been published in professional teachers magazines. His science teacher preparation classes are known for using innovative approaches to teacher preparation.

Understanding Force and Motion

Chapter 1

Contents

Scientific Explanation

The objects will not change position from their initial rest positions because the downward force on each side of the pulley (ignoring the weight of the string) is the same and the net force on each side of the pulley is zero. The gravitational attraction is the same on each object. An object remains in constant motion (or at rest) unless a net force greater than zero acts on it. This is Newton's first law of motion.

Students' Explanations: Field Experience

This POE was used with 40 grade 7 students. Fifty-seven percent (57%) predicted correctly that the objects would not move (a), 35% predicted (b), and 8% predicted (c). Those predicting correctly, (a), often were able to articulate an explanation that was scientifically acceptable:

> ***I think it is (a) because gravity is pulling down on them and since they weigh the same there will be equal force and they won't move.***

And, very perceptively,

> ***There is more weight on the one that is lower because there is more string.***

A few introduced the idea of friction:

> ***I think (a) is true because there is friction on the rope and this stops movement.***

The types of preconceptions underpinning incorrect predictions were as follows. Many students seemed to think of the pulley system as a pair of scales:

> ***The weights are equal and they want to be at the same height.***

A few explained their observations in terms of gravity varying with height:

> ***The gravity on the top will have a greater pull on it so this (c) will happen.***

Students' Explanations: Research Findings

Seventy-eight percent (78%) of 125 14-year-olds thought that the unaided objects would move until both were at the same level. For some, this was a normal consequence of the objects being equal:

> ***The objects are the same weight so they will lift each other to the same height.***
>
> ***Both weigh the same but if one weight is pulled slightly over to one side, the other will be able to even it out.***
>
> ***Because when the short side is pulled toward the Earth and when they are even there is no force so they don't move.*** **(Watts and Zylbersztajn 1981)**

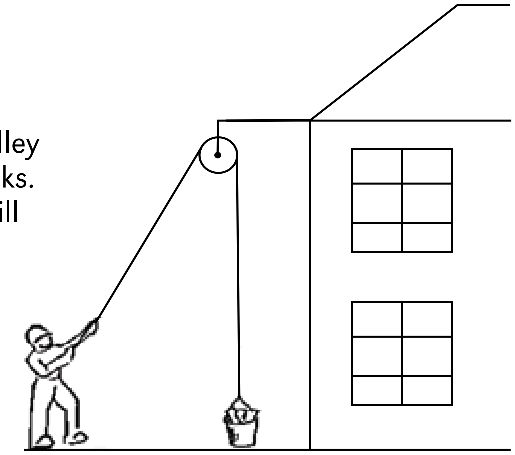
Similar research was carried out with 466 first-year university students (Gunstone and White 1981). Thirty-five percent (35%) predicted that the system would return to the original position, with the objects at the same level. Only a few (13%) of those predicting incorrectly were able to reconcile their observations scientifically.

Apparatus and Materials

- Stand
- Clamp
- Pulley
- 2 equal masses
- String

Note: Gunstone and White (1981) favor using a bicycle wheel instead of a pulley and a bucket of sand and a wooden block instead of the objects. This suggestion has much to recommend it. Set up the apparatus so that the two objects are at the same height, Position B. To begin the experiment, pull one mass down to Position A.

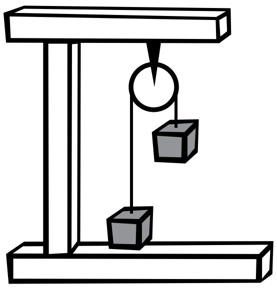
Balanced Forces



The Bricklayer's Problem

A bricklayer is building a chimney. He sets up a pulley at the edge of the roof. He fills the bucket with bricks. It weighs the same as he does. He wonders if he will be able to lift it. Can he haul it to the top? He tries!

An Experiment

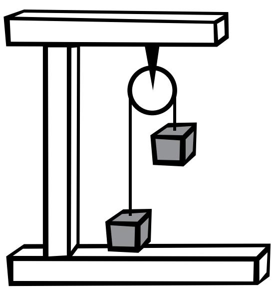


Attach two equal objects to a piece of string and loop them over a pulley as shown in the diagram. Let go of the bottom object and wait one minute to see if anything happens. What do you predict will happen?

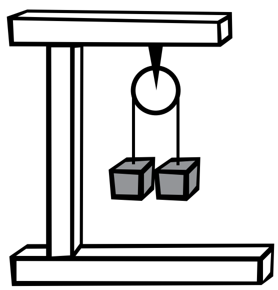
Predict

Which drawing below do you think will show the position of the objects one minute from now? Check one [√].

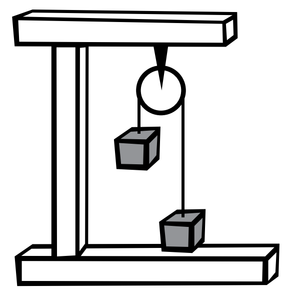
(a)



(b)



(c)



Please explain.____

____

____

Observe

What happens when you do the experiment?

____

Explain

Try to explain what actually happened.

____

____

____

Scientific Explanation

In the "pulley problem," there is no movement. The downward (gravitational) force on each side of the pulley must therefore be the same. The mass of the bucket of sand and the mass of the wooden block are therefore the same. (Newton's first law of motion states that an object will continue to move at a constant speed [or remain at rest] unless it is acted upon by a net force greater than zero.)

If just a little sand is added to the bucket, the downward force on that side is greater; however, there will be no movement if it cannot overcome the frictional force between the pulley and its axle.

If more sand is added, the downward force increases and the bucket begins to move when the frictional force is overcome.

Because the bucket accelerates, the speed at Point B is greater than at Point A. If even more sand is added, the acceleration is even greater. (Newton's second law quantifies the relationship between force and acceleration: $F = ma$).

Students' Explanations: Research Findings

This POE is based on research done by Gunstone and White (1981) with first-year university physics students.

1. In the "pulley problem," 27% of students thought the block would be heavier. Some attributed this to the block being closer to the floor.
2. Just more than half made correct predictions about what would happen when sand was added; however, 30% predicted a "new equilibrium" position would result, as if position and not just net force affected the system.
3. Ninety percent (90%) of students correctly predicted that the speed of the bucket would be greater at the lower mark.

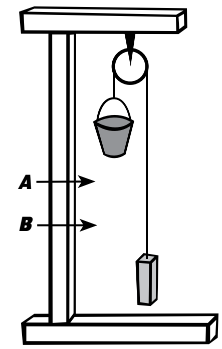
A similar study by Hakkarainen and Ahtee (2005) found that the majority of students in grades 5 through 9 thought that the lower-hanging object was heavier.

Apparatus and Materials

- Pulley (or bicycle wheel)
- Cup (or bucket) of sand
- Block of wood
- String (or cord)
- Stand and clamp

Note: Before carrying out the experiment, demonstrate that the pulley or bicycle wheel moves freely, and that the block and bucket can pass without bumping each other. Check that the apparatus is stable.

Balanced and Unbalanced Forces



Pulley Problem
A bucket of sand and a block are connected by a string. The string is then placed over a pulley so that the bucket is higher than the block. Nothing happens!

Question: Which do you think is heavier? Check one [√].

(a) Bucket **[ ]** (b) Block **[ ]** (c) About the same **[ ]**

Please explain. ______________________________

____

Two Experiments
1. Add a small amount of sand to the bucket.
2. Add a larger amount of sand to the bucket.

Predict
What do you think will happen in each experiment? Do you think the block will move? Please explain.

Experiment 1: ______________________________

____

Experiment 2: ______________________________

____

Observe
What happens?

Experiment 1: ______________________________

Experiment 2: ______________________________

Explain
Try to explain what happened.

Experiment 1: ______________________________

____

Experiment 2: ______________________________

____

Hey!
Do you think the bucket will move faster as it passes Point A or Point B, or will the speed be the same? Please predict and explain. ______________________________

____

Let's take a closer look! ______________________________

Scientific Explanation

The two carts apparently experience the same gravitational force. There would be, theoretically, an extremely small but imperceptible difference: The gravitational pull between two objects decreases as the distance between them increases. Because the upper cart is slightly farther away from the center (of gravity) of the Earth, the force acting on it is slightly, albeit immeasurably, less.

Students' Explanations: Field Experience

This POE was used with 34 grade 7 students. Their predictions were as follows: 38% believed that the upper cart would experience more force on it (a); 12% believed that the lower cart would experience more force on it (b); and 50% thought that both carts would experience the same force (c).

Many reasons were given for both carts experiencing the same force: same mass, same weight, same slope, same friction, same gravitational pull:

> ***... because there is the same amount of mass.***
>
> ***... because they are both carrying the same amount of weight and it has the same force.***
>
> ***... because both are on the same angle, both the same car, same amount of friction.***
>
> ***Gravity is the same wherever the car is.***

There appeared to be three major reasons underpinning incorrect predictions. Some students believed gravitational pull varied with height:

> ***The higher the car, the more force of gravity will be on it.***

Other students felt differently:

> ***... because the top cart is higher and gravity is far away.***

Some students perceived that the slope of the ramp was greater at the top:

> ***The top one has a steeper hill to get down.***

Some students associated the force on the cart with the speed the carts would have at the bottom of the hill if released:

> ***... because it is higher up and will have more force and speed. The lower won't have enough time to pick up speed.***

Students' Explanations: Research Findings

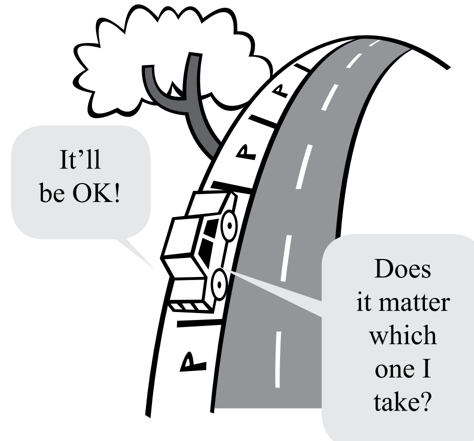
Forty-eight percent (48%) of 125 14-year-old students chose the option suggesting that the upper car would be pulled down the hill with a greater force than the other (Watts and Zylbersztajn 1981):

> ***... because the car is farther up the hill and will have more force pulling it down.***
>
> ***... because the car is higher there is a bigger force.***
>
> ***... if you are lower the force is weaker.***
>
> ***The hill is very steep and gravity pulls things down to Earth ... is much higher so the force is greater.***

Apparatus and Materials

- Meter board or plank
- Dynamics cart or toy truck
- Weight (e.g., 500 g)
- Force meter

Parking on a Hill



The only place to park the car was on a very steep hill.

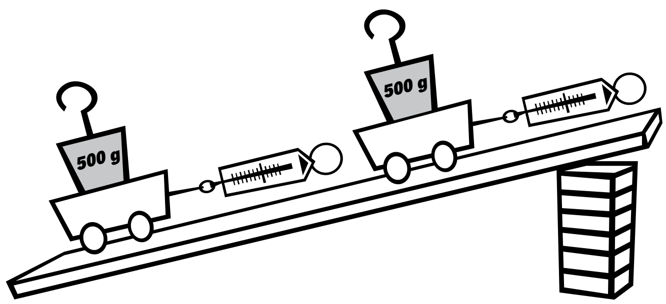
"It'll be OK if you put on your emergency brake and turn in your wheels," Jesse said to her mom.

There were two parking spots available: one halfway down, the other toward the top.

"Do you think it matters which one I take?" Jesse's mom asked.

An Experiment

Set up a board on an angle (about 30 degrees). Put two carts each containing the same mass (say 500 g) on the board (as shown) and attach force meters to them. Read the force on each cart.



Predict

Which of the following statements will be true? Check one [√].

(a) [ ] The upper cart experiences more force on it.

(b) [ ] The lower cart experiences more force on it.

(c) [ ] Both carts experience the same force.

Please explain your thinking. ____

____

____

Observe

Attach the force meters to the carts and read the force each registers. Write down your observations.

Force on upper cart ______________ Force on lower cart ______________

Explain

Try to explain the readings you observed on the force meters. ______________________

____

____

Scientific Explanation

The washer is kept in circular motion by the force of the string pulling it toward the center. The washer, once released from the pulling force of the string will continue in a straight line (tangential to the circular path)—that is, it will follow Path B. Newton's first law states that an object will continue to move in a straight line unless acted on by a force.

Students' Explanations: Research Findings

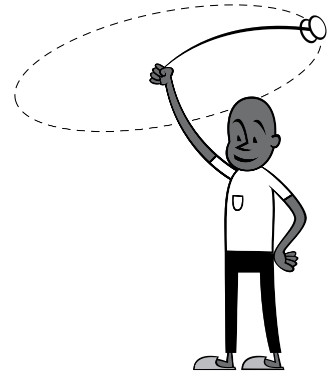
Fifty-one percent (51%) of college undergraduates interviewed by McCloskey (1983) predicted correctly.

A similar study was carried out with 315 grade 9 students (Berg and Brouwer 1991). The majority of the students theorized that a "circular force" would be given to the object and that it would therefore continue in a circular path.

Apparatus and Materials

- Piece of string (15 cm long)
- Washer

Sling Shot



Have you ever whirled something around your head on the end of a string?

What would have happened if the string broke?

An Experiment

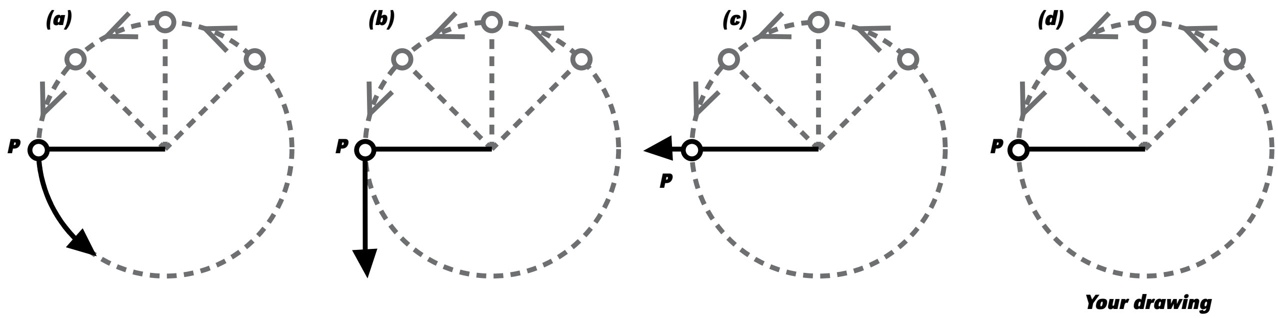
Tie a washer to the end of a 15 cm piece of string.

Twirl the string around and let it go.

Predict

Which path do you think the washer will take when it is let go at point P? Check one [√].

Or if none of these fit your thinking, draw your own direction arrow on (d).



Please give your reasons. ______________________________

____

____

____

Observe

Let's give it a go! Be careful not to hit someone with the washer, though!

What happens? ______________________________

Explain

Can you explain why the washer went in the direction it did?

____

____

____

Scientific Explanation

Keep it going: It usually requires very little force to keep a trailer going—just enough to overcome the friction between the wheels and the axles. (You can coast on a bicycle for a long way.) Newton's first law says that an object will continue to move in a straight line at constant speed unless it is acted on by a force.

Speeding up: If you apply a constant force to the trailer, it will speed up, provided, of course, that the force is greater than the friction. (You speed up on a bicycle when you pedal. It is only when friction and air resistance balance your push that you reach maximum speed.) When you apply a force to a moving object, it accelerates. This is a natural extension of Newton's first law.

Double the pull: If you double the pull or the force applied, the acceleration is doubled. (If you push harder on your pedals, your bicycle will accelerate faster.) Newton's second law says that the acceleration (a) is proportional to the force (F) applied. It is often expressed in the form $F = ma$, where m is the mass of the object.

Double the load: Doubling the load increases the mass of the trailer. Hence, applying Newton's second law, the trailer does not accelerate as fast. (A heavy cyclist will have to push harder than a lighter one to accelerate as fast.)

Downhill disaster: The two trailers reach the bottom of the hill at more or less the same time. (Different frictional resistance accounts for any variation). The effect of doubling the pull is balanced by the effect of doubling the load. (Ignoring any difference in friction, a heavy cyclist coasting down a hill will reach the bottom at the same time as a lighter one.)

Note: The same reasoning explains why all falling objects accelerate at the same rate.

Students' Explanations: Field Experience

We noticed that students encountered considerable difficulty when being taught this topic, so we devised this POE to help them, hoping that they would find it less counterintuitive.

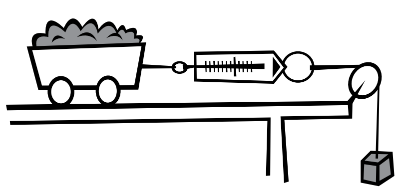
Students' Explanations: Research Findings

In their review of children's ideas about force and motion, Gunstone and Watts (1985) identify five intuitive rules that children frequently use. Two of these are pertinent here: First, many students hold the so-called Impetus Theory of Motion. This intuitive rule says that "constant motion requires a constant force." For example,

> ***If he wanted to keep moving along here (the horizontal), he would have to keep pushing, otherwise he'd run out of force and just stop.***
>
> ***To keep going steadily, you need a steady push. If you don't force something to move, its not going to go along is it? (13-year-olds)***

Second, many students also believe the following rule, which is an extension of the first idea: "[T]he amount of motion is proportional to the force" (or the harder you push something, the faster and farther it goes). Findings of this type are remarkably stable over time and across cultures and are identified with what is known as an Aristotelian framework that comes from basic intuitive models grounded in children's everyday lived experiences (Mildenhall and Williams 2001). These models are generally non-Newtonian (and, consequently, noncanonical) understandings of mechanical relationships and are remarkably resistant to change (Mildenhall and Williams 2001).

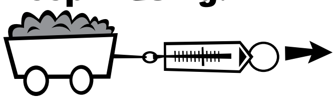
Apparatus and Materials



- 2 dynamics carts
- String
- 1 Newton force meter
- Set of weights
- Table pulley
- Board (about 1 m long)
- Blocks (to make an inclined plane)

Towing a Trailer

Keep It Going!



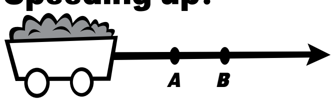
True or false? Once the trailer is moving, it takes next to nothing to keep it going (at constant speed).

Predict ________ Observe ________________________________

Explain ________________________________

____

Speeding up?



True or false? If you pull with a constant force, the trailer speeds up (that is, moves faster at B than A).

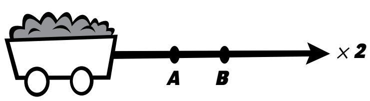
Predict ________ Observe ________________________________

Explain ________________________________

____

Doubling the Pull

True or false? If you double the pull, the trailer speeds up (accelerates) twice as fast.



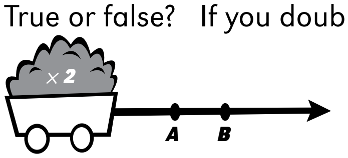
Predict ________ Observe ________________________________

Explain ________________________________

____

Doubling the Load

True or false? If you double the load, the trailer doesn't accelerate as fast.

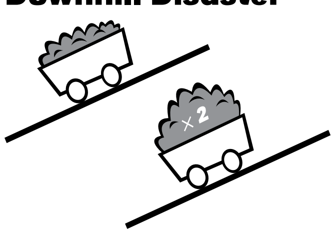


Predict ________ Observe ________________________________

Explain ________________________________

____

Downhill Disaster



True or false? If two trailers break free and roll back down a hill, the trailer with double the load reaches the bottom at more or less the same time as the trailer with a single load.

Predict ________ Observe ________________________________

Explain ________________________________

____

Scientific Explanation

It's the blowing force that makes the seeds move. In the larger tube, the force acts for a longer time. Hence the seed continues to accelerate, builds up more speed, and goes farther.

Note: This POE can also be used when considering energy concepts. The expanding gases do more work in the longer tube (work = force × distance). Hence, more kinetic energy is produced in the longer tube.

Students' Explanations: Research Findings

In their review of children's ideas about force and motion, Gunstone and Watts (1985) identify five intuitive rules that children frequently use. Two of these are pertinent here.

First, many students hold the so-called Impetus Theory of Motion. This intuitive rule says that "constant motion requires a constant force":

> ***If he wanted to keep moving along here (the horizontal), he would have to keep pushing, otherwise he'd run out of force and just stop. (13-year-old)***
>
> ***To keep going steadily, you need a steady push. If you don't force something to move, its not going to go along is it?***

Second, many students also believe the following rule, which is an extension of this statement: "The amount of motion is proportional to the force" (or the harder you push something, the faster and farther it goes).

Hakkarainen and Ahtee (2006) stress the importance of pupils' experiencing the same concept in different contexts for them to reach understanding.

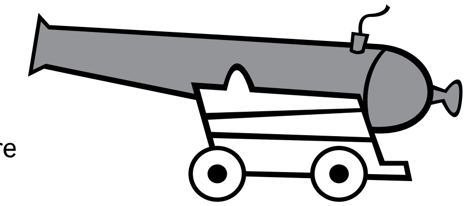
Apparatus and Materials

- Plastic straws
- Sunflower seeds
- Scissors

If you wish to explore the effects of force acting for a longer time, you will need the following items:

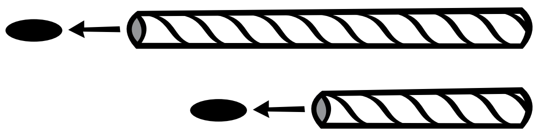
- Truck or dynamics cart
- 100 g weight
- Table pulley
- String

Sunflower Shooters



Susan was watching a show about World War II. She was amazed at the artillery that was used at the front. The gun barrels were so long! Could it be that the long barrels are more accurate? Maybe they are more powerful. What do you think?

An Experiment



Take a plastic straw and cut a piece off the end about 5 cm long. Blow a sunflower seed out of it and see how far it goes. Try blowing a sunflower seed out of a regular straw and observe how far the seed goes.
Note: Both straws should be horizontal.

Predict

What do you predict will happen? Check one [√].

(a) **[   ]** The seed will go farther using the short straw.
(b) **[   ]** The seed will go farther using the long straw.
(c) **[   ]** They will go the same distance.

Please explain your thinking. ____

____

____

____

Observe

Let's be fair! Color the seed in the long straw red and the seed in the short straw blue, then launch both at the same time. Which straw shoots farther?

____

Explain

Try to explain the results of your experiment. ____

____

____

____

____

Scientific Explanation

When we walk, our feet push on the ground, the ground pushes back on us, and we go forward. A push in one direction is matched by a push in the opposite direction. Forces always come in pairs. When the rope was attached to the tree, the tree was pulling as hard on the rope as the students were pulling on it. Try holding one end of the rubber band: You will be acting as if you are the tree. (In passing, we have found it useful to do this with students—it seems to help them.) Newton expressed these ideas in general terms in his third law of motion: For every action there is an equal and opposite reaction. Or if Body A puts a force on Body B, then Body B puts an equal force on Body A, but acting in the opposite direction.

When both teams are pulling and the rope is stationery, Team A will be pulling as hard as Team B. In the experiment, the rubber band is the same length as when one team is practicing. It may seem strange, but the same is true when Team A is moving slowly and steadily (Newton's first law). Interestingly enough, the team that is able to push harder on the ground is the team that wins! You can check this by adding a small weight to one team. You will notice two interesting things: (1) The length of the elastic remains the same, and (2) the whole apparatus begins to accelerate (Newton's second law).

Students' Explanations: Field Experience

In the trial, a spring scale was used instead of the elastic band and a 5 N force applied to each end. However, it was subsequently modified because we found that the way a spring scale works sometimes puzzles the students.

When this POE was used with 86 grade 7 students, their predictions were as follows:

Nineteen percent (19%) predicted that the scale reading would be 0 N. Typically these students reasoned that the forces at each end of the scale would balance out:

> ***I think it will measure 0 N since there's balanced forces working on it not allowing it to be pulled either way.***

Thirty-one percent (31%) predicted that the scale reading would be 10 N, typically arguing that both the forces would act on the scale:

> ***(10 N) because there is 5 N on each side pulling it.***

Forty-three percent (43%) correctly predicted that the scale reading would be 5 N. Some evidently found it difficult to articulate their reasons:

> ***I think it will read 5 N. I don't know why. I just think it will.***

Others were able to express their thinking very clearly:

> ***I think it will weigh 5 N because one side will hold it while the other side puts weight on it.***

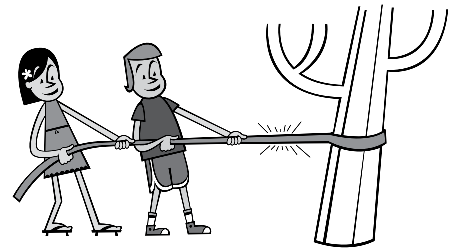
Students' Explanations: Research Findings

Watts and Zylbersztajn (1981) tested 125 students who were 14 years old. They found that 82% of the students believed that the team exerting the greater force on the rope would win. None of the students mentioned the forces between the people and the ground.

Apparatus and Materials

- 2 pieces of string (paper clips fastened to each end enable them to be clipped on and off quickly)
- 2 identical weights
- 2 table pulleys
- Elastic band
- Ruler

Tug-of-War



The A Team was practicing for the tug-of-war. They tied the rope to the large oak tree in the field behind the school. The tree held up, but the rope looked as if it would break.

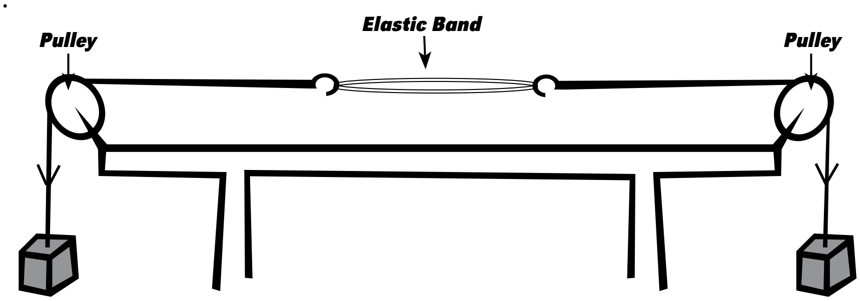
"With both teams pulling, I bet the rope will break when they use it in the tournament!" Joey laughed.

What do you think?

An Experiment

First, hang a weight from an elastic band. Measure the length of the stretched elastic. _____ cm

Then set up the apparatus below. Attach a second weight (same mass) to the other end of the elastic band.



Predict

Do you think the elastic will stretch **[ ]** More **[ ]** Less **[ ]** The same? Check one [√].

Don't forget to explain your thinking. ____

____

____

Observe

Let's check! How long is the elastic band now? ______ cm

Explain

Try to explain what actually happens. ____

____

____

Hey!

So, do you think the rope will break in the tournament?

Try these brainteasers! The A Team is winning! They are slowly moving backward.

Do you think the elastic will stretch if you slowly pull one end of the string?
Prediction _____ Observation _____

Describe carefully what you think will happen if you add a small weight to one end. __________

____

Let's try it! ____

Scientific Explanation

The golf ball and the Ping-Pong ball appear to hit the ground at the same time. Similarly, the legend about Galileo culminates with the two balls hitting the ground at the same time. However, even though the legend often appears in science textbooks, it is almost certainly fiction. Nevertheless, it was Galileo who carried out some brilliant experiments with inclined planes. These led him to the conclusion that the acceleration of all falling objects is the same.

Because gravitational force acts continuously on an object as it falls, the object falls faster and faster. It accelerates. The two balls hit the ground at essentially the same time. This can be explained by Newton's second law: $F = mg$, where F equals the force on an object, m is the object's mass, and g is the acceleration due to gravitational attraction. This can also be expressed as $F/m = g$; because the ratio of force to mass is constant, all objects dropped from the same height should hit the ground at the same time.

Many people find this hard to believe. They know a piece of paper falls to the ground slower than a book. Indeed, if the two balls were dropped from a higher elevation, another factor would be seen to come into play. This is air friction. The friction the falling object encounters slows the acceleration until, given some time, the force of air friction, which increases with speed, equals the force due to gravity. At that point, the object doesn't speed up because there is no net force on it (in accordance with Newton's first law). It falls at a constant speed—its terminal velocity. The Ping-Pong ball will be slowed down faster than the golf ball because it is lighter. If you dropped the two balls from a second-floor window, the golf ball would hit the ground first!

Students' Explanations: Field Experience

This POE was used with 42 grade 7 students. Eighty percent (80%) predicted that the golf ball would hit the ground first. The majority of these attributed this to the golf ball being heavier. One articulate student put it this way,

> ***The golf ball will hit the floor first because it is heavier than the Ping-Pong ball so the gravitational force is stronger on the golf ball.***

After the students had observed the balls hit the floor at the same time they evidently struggled to construct reasons, e.g.,

> ***They were the same when they fall because of buoyancy.***
>
> ***They have about the same surface and no wind effecting [sic] them.***
>
> ***... because of the same gravitational pull. And the wind or air couldn't interfere.***

No students were able to provide a scientifically acceptable explanation.

Their teacher was clearly concerned and wondered if this POE should be used only after Newton's laws had been taught. She also was concerned about how to present the scientific explanation.

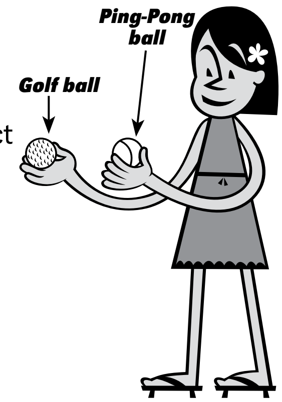
Students' Explanations: Research Findings

In a study of 67 grade 5 students, Nachtigall reported that 91% expected a heavier ball would fall faster and that 47% described the fall as being at a constant speed on account of the force of gravity being constant (see Driver et al. 1994). Gunstone and White (1981) reported that 25% of 176 first-year university physics students thought that an iron ball would fall faster than a plastic ball: 10% because it weighed more, 15% because of air resistance.

Apparatus and Materials

- Golf ball
- Ping-Pong ball

Which Falls Faster?



Galileo and the Leaning Tower of Pisa

About 400 years ago, scientists were arguing about whether a heavy object would fall at a different speed than a light one. There is a legend that Galileo and his students took two lead weights of different masses to the top of the Leaning Tower of Pisa in Italy and dropped them off at the same time!

What do you think they would have observed?

An Experiment

Hold a Ping-Pong ball and a golf ball out in front of you. Drop them at the same time.

Predict

What do you think will happen? Check one [√]. Don't forget to explain your thinking!

(a) **[ ]** The Ping-Pong ball will hit the floor first.

(b) **[ ]** The golf ball will hit the floor first.

(c) **[ ]** They will both hit the floor at the same time.

____

____

____

Observe

Describe what you see. ____

____

Explain

Can you explain what happened when the two balls were dropped?

____

____

Hey!

Did you observe carefully? Do you think the balls fell at a constant speed, or did they fall faster and faster? ____

Take a second look! What happens?

____

____

____

Scientific Explanation

Answers to Quick Quiz

(a) When the Ping-Pong ball and the golf ball are dropped from shoulder height, they apparently hit the ground at the same time (see FM8).

(b) When dropped from 5 m, the golf ball hits the ground first.

(c) The book hits the ground first.

(d) The coin hits the ground first.

Take the air away and the coin and feather will fall at the same rate. (Galileo was right!) If you dropped the coin and feather on the Moon, where there is no air, you would see them hit the ground at the same time.

When a piece of paper is put on top of a book, it is shielded from the air resistance and hence falls at the same rate as the book on which it is resting

Students' Explanations: Field Experience

The responses of 30 grade 7 students to this POE were analyzed. Seventy-three percent (73%) correctly predicted that both the penny and feather would hit the bottom at the same time, and the majority of these students reasoned in terms of air resistance. However some appeared to believe that air resistance only affected the feather:

> ***… 'cause there is no air resistance to hold the feather back.***

Two students, predicting correctly reasoned in terms of buoyancy:

> ***I think they will both reach at the same time because the feather falls slower.***
>
> ***… (when there is air) because it is so light but it will be heavier.***

Most of those who predicted that either the penny or the feather would hit the bottom first reasoned in terms of the heaviness of objects. After observing, they attempted to reconstruct their thinking in terms of the effects of the air:

> ***… because there was no air pressure to stop the penny and the feather.***

Apparatus and Materials

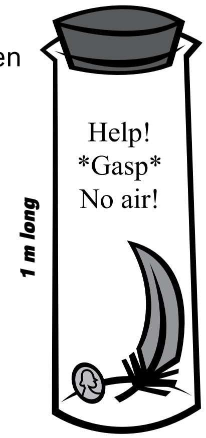
You can purchase the coin and feather apparatus from a number of scientific supply companies.

Feather and Coin Mystery

Quick Quiz
Which hits the ground first?

(a) A Ping-Pong ball or a golf ball, dropped from shoulder height ______________________
(b) A Ping-Pong ball or a golf ball, dropped from 5 m ______________________
(c) A book or a piece of paper, dropped from shoulder height ______________________
(d) A feather or a coin, dropped from shoulder height ______________________

An Experiment
Here's a tube about 1 m long. It contains a penny and a feather. All the air has been sucked out. What do you think will happen when the tube is turned upside-down?



(a) The feather will reach the bottom first.
(b) The penny will reach the bottom first.
(c) They will reach the bottom at the same time.
(d) They won't fall and will just float.

Predict
What do you predict: (a), (b), (c), or (d)? Explain your thinking for your prediction.

____
____
____

Observe
If your school doesn't have this apparatus, your teacher will tell you what happens.

____

Explain
How can we explain what actually happens? ______________________
____
____

What Happens?
Place a piece of paper on top of a book. Which do you think will fall faster, the book or the paper? Let's do it! Try to explain what happens!

____
____
____
____

Scientific Explanation

The key to making a correct prediction is to realize that the only force acting on both coins, once they have been launched, is gravity (that is, if one ignores air resistance); hence, both coins accelerate toward the ground at the same rate. Indeed, because the rate of acceleration is independent of mass, coins having different masses would likewise hit the ground at the same time. (This might make an interesting extension to this POE.)

Although the flicked coin launched horizontally had a force applied to it immediately before takeoff, this force stopped once it had left the launcher. According to Newton's first law, it would have continued to move horizontally at constant speed unless acted on by another force.

Students' Explanations: Field Experience

This POE was used with 25 grade 7 students. Forty-four percent (44%) thought the dropped coin would hit the ground first. Nearly all reasoned in terms of the flicked coin having farther to travel:

> ***... because the one flicked will have to go out and down and the other will go straight down.***
>
> ***The dropped coin would hit first because it's going straight down.***

Twenty percent (20%) thought that the flicked coin would hit the ground first. All reasoned in terms of the coin traveling faster:

> ***I think the flicked one will hit first because it is going faster.***
>
> ***It will go down faster because more force is applied to the coin.***

Thirty-six percent (36%) predicted correctly that they would hit the ground at the same time. All appeared to appreciate that the horizontal motion had no bearing on the vertical rate of fall and argued in terms of their having the same distance to fall, gravitational force being the same, their mass or weight being the same, or air resistance being the same:

> ***They will hit the ground at the same time because they have the same amount of distance to go.***
>
> ***... because the same amount of gravity is pulling on them.***
>
> ***... because they still have the same weight and mass so they fall at the same speed.***
>
> ***They will hit at the same time because they have the same amount of air resistance and mass.***

We don't know if those who said they would hit at the same time because their mass or weight was the same realized that these factors do not determine the rate at which an object falls.

Students' Explanations: Research Findings

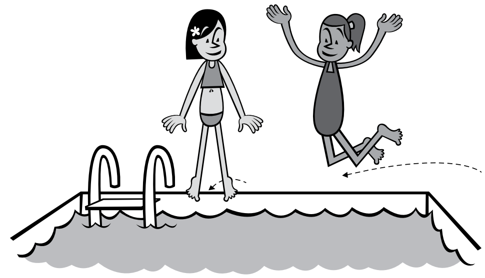
There have been a number of studies of students' thinking about the forces acting on objects in motion. For example, Watts and Zylbersztajn (1981) asked 14-year-old students to identify the forces on a cannonball in mid-flight and on a stone that had been thrown upward.

Eighty-five (85%) thought that there would be a force on the cannonball away from the cannon and an upward force on the stone. In sum, they held the belief that if an object is moving, then there is a force acting on it in the direction of motion. Forces from other directions are not always recognized, as demonstrated in the research by Palmer (2001) in which many students did not believe that gravity does not act on objects that are moving upward.

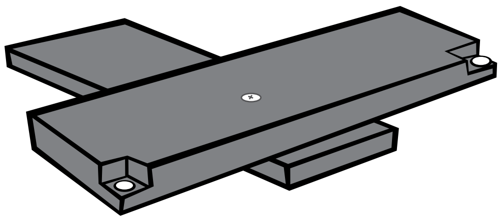
Apparatus and Materials

Construct a coin launcher similar to the one in the diagram, or you can practice pushing and flicking the coins off a table at the same time. The coin launcher is made from two pieces of wood (plywood works well). One has a hole drilled in the middle and is mounted on the other piece using a nail or screw.

Coin Launcher



At the Pool
Gina and Susan were at the pool. Gina took a running leap off the edge of the pool, and at the same time Susan stepped off the edge and dropped into the pool. Who do you think will hit the water first?



An Experiment
This simple homemade apparatus is designed to help you launch a coin and drop one at the same time. Place two coins on the apparatus as shown in the diagram. Place the apparatus on the edge of a table and flick one side. Which coin do you think will hit the floor first?

Predict
Check one [√].

The dropped coin will hit first. **[ ]** The flicked coin will hit first. **[ ]**

They will hit at the same time. **[ ]**

Please explain your thinking. ______________________________

____

Observe
Watch and listen as the two coins hit the floor. What happens? ______________

Explain
Try to explain your observations. ______________________________

____

____

____

Let's Try This!
What do you think would happen if we used different coins (e.g., a quarter and a nickel) on the launcher. Please explain.

____

____

____

____

Scientific Explanation

The wrench will fall to the surface of the Moon. The force of gravitational attraction between the Moon and any object on it is about one-sixth of that on the Earth. On the Moon objects fall (accelerate) at about one-sixth of the rate on Earth.

In general, any two objects attract one another. This is called *gravitational attraction*. The more massive they are or the closer they are, the larger the attraction.

Note: If the flag was a regular flag it would just hang limply. There is no air on the Moon to make it flutter, and gravitational force would take over. Hence, it must be a "fake" flag. Perhaps it has wire along the top, which makes it appear to fly.

Students' Explanations: Research Findings

Watts and Zylbersztajn (1981) found that 80% of 125 14-year-old students thought the wrench would either move upward or remain stationary at hand height. Their reasons were manifold. Here is a sampling of the answers:

> ***There will be no force because there is no gravity or atmosphere.***
>
> ***There is no gravity on the Moon so there is no force.***
>
> ***On the Moon there is no gravity. Gravity pulls things down to Earth. If there is no gravity the object must go up.***
>
> ***It would be pushed up by the force of the Moon air.***
>
> ***In space everything is supposed to be lighter, so it will float up like a gas balloon.***

This study was repeated by Berg and Brouwer (1991). They found that the majority of 315 grade 9 students believed that there was no gravity on the Moon because there was no air. Many thought that the wrench would move away from the moon. Galili (1995) similarly found that "students, especially at the lower educational level, tend to associate the *cause* of gravity with air pressure" (p. 63).

Apparatus and Materials

No materials necessary

Accident on the Moon

In the Past ...

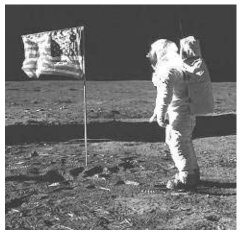
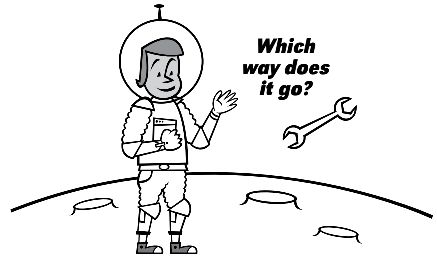


Photo provided by NASA

In 1969, Neil Armstrong became the first person to set foot on the Moon. He left the American flag planted on the Moon's surface for all to see and remember. Armstrong took this photo of fellow astronaut Buzz Aldrin next to the flag.

In the Future!



Imagine yourself as an astronaut on the Moon. By accident, you let go of a wrench. What do you think will happen to the wrench? Will it move? In which direction?

Predict

What do you think will happen to the wrench? Please give your reasons!

____

____

____

Observe

Neil Armstrong would have been able to tell you what would have happened. Your teacher also knows. Write down what you would observe.

____

Explain

How would you like to change the reasons for your prediction?

____

____

____

Check It Out!

Take a close look at the flag in the picture. Is there something strange about it? How would you explain the way it is "fluttering"?

____

____

____

Scientific Explanation

There are two possible cases that scientists would likely consider: (a) **no air present** in the hole (this is the one students will likely consider), or (b) **air present** in the hole (this might be worth discussing with the students afterward).

(a) **No air present**. Because there is gravitational attraction between the ball and the Earth, *the ball begins to drop into the hole. It drops faster and faster until it reaches the center of the Earth*. Here the Earth pulls on the ball equally in all directions. *After it has passed the center, the ball begins to slow down* because the gravitational force is pulling it back into the hole. *The ball finally stops moving just as it comes out the other side. It is then pulled back into the hole again. It will continue to go backward and forward forever!*

(b) **Air present.** *The ball begins to drop into the hole—but not as fast as before* because of air resistance. *After a few seconds, the ball reaches its terminal velocity:* the gravitational attraction for the Earth being balanced by air resistance. *It then begins to slow down*, because the gravitational attraction becomes progressively weaker. *As it passes the center it is moving quite slowly. It soon turns back* as the gravitational pull toward the center increases. *The ball continues to move backward and forward but less each time. It finally comes to rest in the center of the Earth*. Note: Observations have been italicized.

Students' Explanations: Field Experience

A similar version of this POE was used with 42 grade 7 students. None of the students considered air resistance. More than 70% thought that the speed of the ball would increase—at least at first—but few appeared to consider what would happen after the ball passed the halfway point:

> ***... the ball will get through if the hole is clear. It will increase because if you drop something, it normally gets faster not slower.***
>
> ***I think the ball will increase in speed because the gravity will force it to speed up. I think the ball will float in the center of the Earth because gravity is equal there.***

Among those who discussed the force of gravitational attraction at the center of the Earth (40%), the overwhelming majority seemed to recognize that gravitational pull is equal there. A number talked in terms of the ball floating in the middle:

> ***The ball will get caught because the two gravitational pulls are equal so it will be a big tug of war.***
>
> ***I think there is no gravity in the center of the Earth. Therefore the ball will not make it to the other side because it will just float around.***

Seventy percent (70%) thought the ball would not reach the other side.

Students' Explanations: Research Findings

Sneider and Pulos (1983) classified students' responses according to their beliefs about gravity. Less than 60% of students in grades 7 and 8 believed that the object would tend to fall toward the center of the Earth. Some thought it would land or float freely at the far edge, some thought it would fly out the other side and go into orbit, and some correctly predicted that it would go back and forth forever if there was no air resistance (see also Nussbaum 1985).

A Hole in the Earth

A Future Situation
Dr. Y has designed a fantastic drill. He decides to drill a hole in the Earth—all the way through!

An Experiment
He asks you to help him with the experiment and gives you a heatproof ball to drop into the hole. Now let it go!

Predict
What do you think will happen? How will the speed of the ball change? Will it get to the other side? Please give your reasons.

Observe
Using the theories that they have developed, scientists are able to tell you what you would observe. Your teacher can tell you, too.

Explain
Try to explain these observations.

Topic: Force and Motion **Concepts:** Frictional forces
The relationship between frictional force and the area of contact

Scientific Explanation

The friction between the block lying flat and the block on its side is the same. Strange as it may seem, the surface area in contact does not make a difference. Only the force between the object and the surface (in this case the weight of the block) and the nature of the surfaces touching each other make a difference. This may be represented by the equation $F = \mu N$, where F is the frictional force, μ is the coefficient of friction between the two surfaces (this varies with the nature of the surfaces), and N is the normal force that the surface exerts vertically on the object (this equals the weight of the object on a horizontal surface).

Apparatus and Materials

- 2 (or more) wooden blocks (e.g., 25 cm length of 2 × 4)
- Force meter

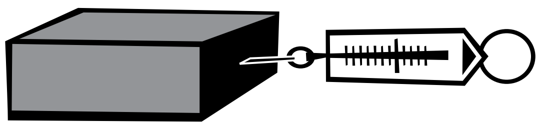
Note: Before carrying out the experiment, you might first like to compare the forces required to pull on the two blocks. (See left-hand side of illustration at the top of the page.)

Reducing Friction?

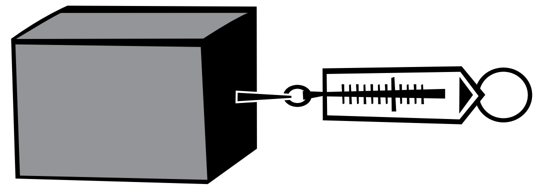
Moving Books

Billy and Jane were helping move the boxes of new books—sliding them over the floor. It was heavy work!

An Experiment



(A) Drag a block at even speed using a force meter



(B) Turn it on its side and drag it again

Predict

What do you think will happen? Check one [√].

(a) [ ] Friction is greater when the block is flat (Position A).
(b) [ ] Friction is greater when the block is on its side (Position B).
(c) [ ] Friction is the same in both positions.

Observe

Let's do it! Record the meter readings when you drag the block.

Position A _______ Position B_______

Explain

Can you make up a rule (hypothesis) that explains what you saw happen? How could you test it?

____

____

____

____

Hey!

What about Billy's idea? What do you think the reading on the force meter would be? ________

Let's try it. Can you explain what happened?

____

____

References

Berg, T., and W. Brouwer. 1991. Teacher awareness of student alternative conceptions about rotational motion and gravity. *Journal of Research in Science Teaching* 21 (1): 3–18.

Driver, R., A. Squires, P. Rushworth, and V. Wood-Robinson. 1994. *Making sense of secondary science*. London and New York: Routledge.

Galili, I. 1995. Interpretation of students' understanding of the concept of weightlessness. *Research in Science Education* 25 (1): 51–74.

Gunstone, R. F., and D. M. Watts. 1985. Force and motion. In *Children's ideas in science*, ed. R. Driver, E. Guesne, and A. Tiberghien, 85–104. Buckingham, United Kingdom: Open University Press.

Gunstone, R. F., and R. T. White. 1981. Understanding of gravity. *Science Education* 65 (3): 291–299.

Hakkarainen, O., and M. Ahtee. 2005. Pupils' mental models of a pulley in balance. *Journal of Baltic Science Education* 2 (8): 26–34.

Hakkarainen, O., and M. Ahtee. 2006. The durability of conceptual change in learning the concept of weight in the case of a pulley in balance. *International Journal of Science and Mathematics Education* 5: 461–482.

McCloskey, M. 1983. Intuitive physics. *Scientific American* 248 (4): 122–130.

Mildenhall, P. T., and J. S. Williams. 2001. Instability in students' use of intuitive and Newtonian models to predict motion: The critical effect of the parameters involved. *International Journal of Science Education* 23 (6): 643–660.

Nussbaum, J. 1985. The Earth as a cosmic body. In *Children's ideas in science*, ed. R. Driver, E. Guesne, and A. Tiberghien, 170–192. Buckingham, United Kingdom: Open University Press.

Palmer, D. 2001. Students' alternative conceptions and scientifically acceptable conceptions about gravity. *International Journal of Science Education* 23 (7): 691–706.

Sneider, C., and S. Pulos. 1983. Children's cosmographies: Understanding the Earth's shape and gravity. *Science Education* 67: 205–211.

Watts, D. M., and A. Zylbersztajn. 1981. A survey of some children's ideas about force. *Physics Education* 16 (6): 360–365.

Index

A

N

R

S

W