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ABSTRACT

The Mathematics, Science, and Technology Educators and Researchers of The Ohio State University (MSaTERs-OSU) is a student organization that grew out of the former Ohio State University Council of Teachers of Mathematics (OSU-CTM). Papers from the fifth annual conference include: (1) "Models of the Structure of Matter: Why Should We Care about What Students Think" (Gordon Aubrecht); (2) "Virtual Reality on the Web: A Vehicle with New Ways to Enhance Spatial Visualization" (Ohnam Kwon); (3) "Developing Identity as Mathematicians through Questioning and Discourse" (Clare V. Bell); (4) "Introduction to Symbolic Mathematics Guide: A Pedagogical Computer Algebra System for High School Algebra Students" (Todd Edwards); (5) "Using the 'I Wonder Journal' as an Example of Open-Ended Inquiry in the Classroom" (Tracy Huziak); (6) "An Analysis of Writing in College-Level Remedial Mathematics" (Drew Ishii); (7) "Integrating Social Technologies with Respect to Calculus: 'Active' Learning and the Group as a Unit of Change" (Robert Klein); (8) "Curriculum and Assessment in the Age of Computer Algebra Systems" (Michael Meagher); (9) "Reform Mathematics within a Traditionally-Structured Course: Using Authentic Mathematical Activity to Investigate Slope-Intercept Form" (Jeffrey Mills); (10) "Components of Effective Professional Development" (Stephen J. Pape and Beth Greene Costner); (11) "A High-Tech Textbook in a Precalculus Classroom" (Jeremy F. Strayer); (12) "Parent Involvement" (Sharon Sweeney); (13) "Stories in Juxtaposition: Narrative Inquiry Research in an Urban School Setting" (Paul Vellom); and (14) "On the Road to a National Dialogue: Standards-Based Education Reform--Is This What We Meant?" (Debra L. White). (ASK)

Proceedings of the
Fifth Annual Spring Conference
of

The Mathematics, Science, and Technology Educators & Researchers of The Ohio State University

MSaTERs

Saturday, May 5, 2001

Arps Hall

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Mission Statement

The ***Mathematics, Science, and Technology Educators & Researchers of The Ohio State University*** (*MSaTERs-OSU*) is dedicated to improving the teaching and learning of mathematics education, science education, and technology education through the following objectives:

- to promote improved teaching practices and research in mathematics education, science education, and technology education;
- to encourage commitment to professional growth and continued professional improvement;
- to promote unity and communication between and among students in mathematics education, science education, and technology education;

Membership is open to all those interested in the advancement of mathematics education, science education, and technology education.

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Models of the Structure of Matter:
Why should we care what students think?

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Abstract

Much of what people "know" about the world is incorrect. Their view of the microworld, the dominant factor in 20th century physics, is misleading to say the least. Some physicists in the OSU Physics Education Research Group have a great interest in studying student understanding of the structure of matter and the interaction of matter with light, with several efforts under way. My students, colleagues, and I have studied student understanding of aspects of quantization, the interaction of light and matter, and radioactivity. I report here on some issues of understanding of the microworld we have found.

Introduction: Why this picture is relevant

Our future generations will inherit from us their understanding of the world around them (see Fig. 1 for some of the citizens of that future world). We need to make sure it is accurate. That understanding of the world is threatened by ignoring the material reality (see Fig. 1) and focusing on myth.

Fig. 1 This picture is relevant for millions of reasons, including the millions of things in it we don't often observe (wood, metal, plastic eggs, real eggs, cloth, dirt, etc.).

I will identify some myths and difficulties facing us, and propose that history of science and public understanding of science can play a crucial role in returning rational thinking to public discourse.

Science vs. Myth

Many people believe in astrology, a "science" discredited long ago. According to Edward J. Boyer and George Ramos [1] writing in the *Los Angeles Times*, "Just as some people swear they are affected by a full moon, many believers in astrology take precautions during a retrograde Mercury. They may back up computer files, not sign any contracts, doublecheck manuscripts for errors or re-confirm appointments." In the *Boston Globe*, Patricia Wen [1] points out "a study by Yankelovich Partners, a marketing research firm, showed 37 percent of Americans believed in astrology in 1997, up from 17 percent in 1976. In the same two-decade period, belief in reincarnation grew from 9 percent to 25 percent, while people who believe in the value of fortune-telling increased from 4 percent to 14 percent." David Perlman,[2] writing in the *San Francisco Chronicle* says ""Accredited" psychics on your TV screen proffer advice for the lovelorn or financially stressed. Sixty-three thousand Internet sites list astrologers and astrological networks. And there are more untested practitioners in varied exotic health fields—iridology, reflexology, aromatherapy—than there are licensed physicians in all the 24 recognized specialties of medicine."

Wen adds more statistics: "A Gallup poll showed that, in 1996, 25 percent of Americans described themselves as very or somewhat superstitious, up from 18 percent in 1990. When it comes to measuring common dreads, 13 percent of Americans fear black cats, 11 percent worry about broken mirrors and 9 percent don't like the number 13." Such is the state of "knowledge" in today's world.

Students are being exposed to "crank" science ideas daily. Much of the problem lies with the voracious media need to fill space or time. It gets filled with "information" which may or may not have content. The website http://www.crank.net/ has a list of many such crank science ideas: crop circles; alternate models of the atom that say "the fleeting particles that are created in bubble chambers and particle accelerators as being fluke events and not actual particles;" belief that static magnetic fields can cure illness; that mercury can be turned into water; and on and on.[3] Longer excerpts of these ideas are presented in Appendix 1.

Many have now heard about the Harvard graduates who did not know why it was warmer in summer (many said that Earth was closer to the Sun in summer), the MIT graduates who could not light a light bulb with a battery and a wire, and people who say "the reactor'll melt its way down through the ground to China ..." or "Don't stand too close to the microwave or the radioactivity will get you."

Is it warmer in summer because Earth is closer to the Sun ? That's hardly the case.

Fig. 2 shows the situation. Earth's orbit is an ellipse, and Earth wanders between its perihelion, at 147.1 million km and its aphelion, at 152.1 million km. Student measurements can show the approximately 7% difference between the intensity of sunlight between these extremes.[4] Before the reader agrees that this 7% difference is the plausible reason for the seasons, consider that the northern hemisphere *winter* occurs when Earth is *closest* to the Sun, and that the northern hemisphere *summer* occurs when Earth is *farthest* from the Sun.

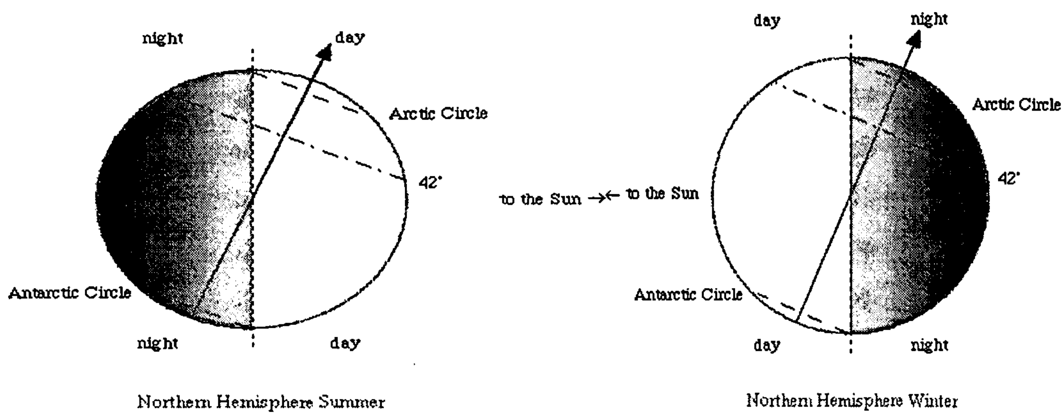


Fig. 2 How summer is warmer. a. In Northern Hemisphere summer, Earth's axial tilt assures more daylight north of the Equator. b. In Northern Hemisphere winter, Earth's axial tilt assures less daylight north of the Equator. In both pictures, 42° north latitude is shown; the 42° south latitude line in in the obvious position.

The seasons are mainly caused by Earth's rotation axis's 23° axial tilt. This tilt is preserved throughout Earth's orbit of the Sun (physicists would speak of conservation of angular momentum). Halfway around Earth's orbit, the tilt angle means the northern half of the globe has the same conditions of sunlight the southern half had six months earlier, and the southern half of the globe has the same conditions of sunlight the northern half had six months earlier.

One may see from Fig. 2 that the 42nd parallel N spends many more hours in daylight than in dark in northern hemisphere summer, and that consequently, the 42nd parallel S spends many more hours in dark than in daylight; it is southern hemisphere winter. This is the real reason for the seasonal difference. With so many more hours of daylight than dark (about 16 hours to 8 hours, a factor of *two*! or 200%) at 42° N, it is summer. With so many fewer hours of daylight at 42° S, it is winter.

Simple explanations also exist for the other misconceptions referred to above. But we are not succeeding in educating our citizens very well. Gary Chapman, writing in the Los Angeles Times,[5] says "While more than 70% of the people the NSF surveyed knew that the Earth revolves around the sun and not the other way around, and that humans and dinosaurs did not coexist, only 16% could define the Internet and only 13% could accurately describe a molecule. At least those numbers are going up, the report's authors noted diplomatically--five years ago, only 11% could define the Internet and only 9% could describe a molecule."

Texts are also problematic. Beaty [6] has a site that lists many misconceptions that appear in elementary school textbooks. A selection of these is shown in Table 1. An Associated Press dispatch "Study Finds Errors in Science Textbooks," 15 January 2001, says "Twelve of the most popular science textbooks used at middle schools nationwide are riddled with errors, a new study has found." The article also said "Researchers compiled 500 pages of errors, ranging from maps depicting the equator passing through the southern United States to a photo of singer Linda Ronstadt labeled as a silicon crystal."

Table 1. Excerpts from "Recurring Science Misconceptions in K-6 Textbooks" by William J. Beaty

The gravitational force in space is zero.
Salt water is full of sodium chloride molecules.
The north magnetic pole of Earth is in the North.
A wing's lifting force is caused by its shape.
Ben Franklin's kite was struck by lightning.
One prism splits light into colors; a second identical prism recombines them.
Light and Radio waves always travel at "the speed of light" —300,000 km/s.
Raindrops have points at their upper ends.
Air is almost entirely weightless.
Shadows vanish on cloudy days because the sun isn't bright enough.
Infrared light is a form of heat.
There are seven colors in the rainbow.
Earth's north and south magnetic poles reside just below the surface.
Cars and airplanes are slowed down by air friction.
Iron and steel are the only strongly magnetic materials.

TIMSS performance

Myth is only part of the problem. Students, at least in the U.S., are performing poorly. Performance of American students on the Third International Science Study (TIMMS) was above the world average at the fourth grade level, just below the world average at the middle school level, and significantly below the world average at the high school level.

The TIMMS report [7] on high school seniors' performance in physics states, "[The] average performance in Norway was comparable to or even exceeded performance at the 75th percentile in ... countries such as ... the United States." In fact, U.S. students' 95th percentile lies at about the Norwegian students' 25th percentile!

Consider the question:[8] A club has 86 members, and there are 14 more girls than boys. How many boys and how many girls are members of the club?

This question was put to many students in different countries. (The answer is that there are 50 girls and 36 boys.) Only twenty-nine percent of US eighth-graders answered this question correctly; 72 percent in Singapore; 66 percent in Taipei, Taiwan; 40 percent in Russia answered correctly.

What is the reason for the sad tale? Diana Jean Schemo [9] writing in the *New York Times*, asked some experts. She points out that "US eighth-grade students are less likely than their international peers to be taught math by teachers who majored in the subject (41% versus 71%). US classrooms attempt to cover many more subjects in a year than high-performing classrooms in other countries. And eighth-grade students spend less time than their international peers studying mathematics or science outside of school. " She quotes Chuck Williams, director for teacher quality at the National Education Association. "Youngsters in urban communities have less chance to have a teacher who is licensed in math and science than in any other area." And, she writes "'Some US teachers have the idea that most kids can't learn algebra; even parents believe it. But that's not true in other countries,' says James Stigler, professor of psychology at the University of California, Los Angeles. 'You end up holding yourself to a lower standard than is necessary, and ultimately that's not good for the nation.' "

What do they know and how do they know it?

A number of the physicists in the Physics Education Research Group at Ohio State University is working on how students understand quantization and the interaction of light and matter and radiation and radioactivity. We use ranking tasks connected to these topics to elicit student responses. We see in our interviews that they usually have no idea about how we know what we think we know.

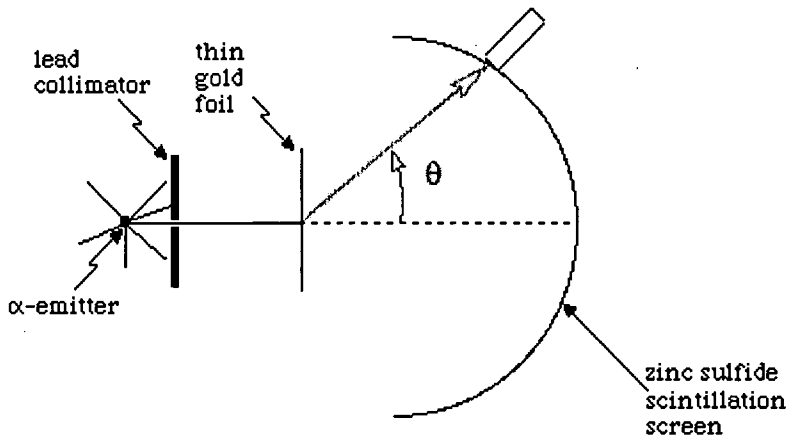


Fig. 3 The Geiger-Marsden apparatus explored Rutherford scattering. The microscope is shown at the end of the α-particle trajectory indicated by the arrow.

One thing we know: The universe is made up of small particles that are gathered into larger assemblies. How do we know? The answer is the Rutherford scattering experiment performed by Geiger and Marsden.[10] The experimental apparatus is shown in Fig. 3. Zinc sulfide is phosphorescent and glows when hit by a particle because it transfers energy to the coating that eventually transfers energy to the electrons in the atoms. These atoms emit light as the electrons deexcite, that is, fall from the excited state to a state of lower energy. The microscope may be moved around the screen to cover the sphere about the target and allow the number of scintillations in a given time to be counted by the experimenters. The researchers expected all the scintillations registered to be in the neighborhood of $\theta \sim 0$ on the basis of the reigning "plum pudding" atomic model, but found that light was emitted for θ near π (180°).

Ernest Rutherford, recalling his response to the news from Geiger and Marsden in 1909, said "It was quite the most incredible event that ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you." He devised the nuclear model as a result.

After Rutherford's lab continued with its work for another two decades, identifying the proton and neutron as constituents of the nucleus, physicists came to a model of the atom as made of just *three* constituents. These are protons, neutrons, and electrons.

Those many things of Fig. 1 are just three! But experimental physics marches on, and subsequently identified the many particles (and more) shown in the particle zoo of Fig. 4.

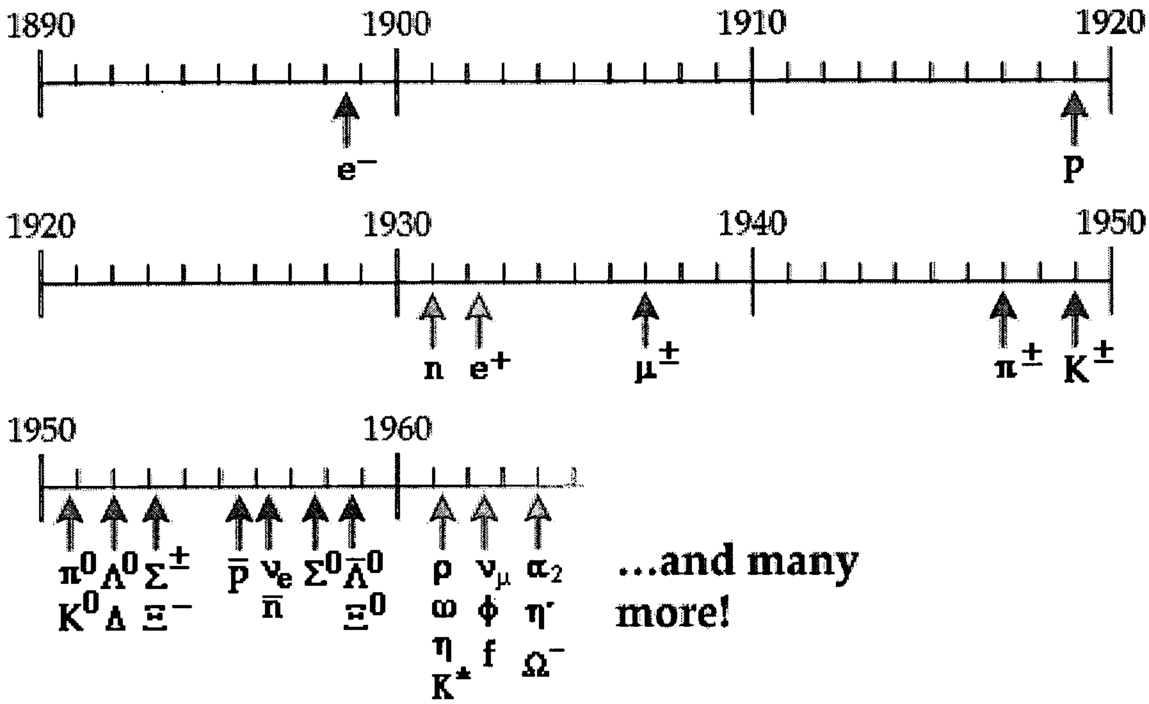


Fig. 4 The particle zoo.

The Contemporary Physics Education Project (CPEP) has provided materials designed to address student and teacher incomprehension of modern physics.[11] CPEP is a non-profit organization of teachers, educators, and physicists located around the world. CPEP materials (charts, software, text, web resources) present the current understanding of the fundamental nature of matter and energy, incorporating the major research findings of recent years. During the last decade, CPEP has distributed over 100,000 copies of its charts and other products. It also maintains a website that supports teaching of contemporary topics.[12]

Four major reasons have pushed us as physics teachers to come to a consensus on including more contemporary topics. First, the conceptual difficulties of contemporary physics are no more challenging for our students than those they already encounter every day in our classrooms. While many modern physics topics are abstract and students do have difficulty in understanding them, classical physics has been shown by the extensive body of research literature [13] to be extremely difficult conceptually. Second, it may excite the curiosity of our students, and emphasize to them that physics is an ongoing process. This may help students see the human side of physics, and make it seem more approachable. Third, despite the addition of "extended versions" of many texts (partly a result of the Fermilab conference on the teaching of modern physics in 1986), students still commonly see no physics beyond 1912 at least until they are second (or often the third) year physics undergraduates. Most students are not physics majors, and thus lose contact with the exploratory spirit characterizing physics research. They may even think that physics is unchanging, totally determined, and boring. Fourth, it is more interesting for teachers to teach about what is currently happening than to repeat the lectures they themselves heard as students. Exciting physics teaching can follow from the excitement a teacher feels about physics, and what is happening now is seen as more exciting than something that happened a century ago.

It is important that students learn how exciting science is, that it is not a study of "dead," dry facts but rather a continuing process. We should not treat physics as a set of facts to be absorbed, but as a growing body of science based on experimental evidence.

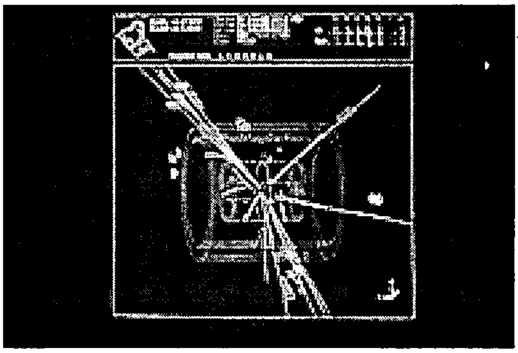


Fig. 5 A detector records the passage of particles.

How do we see inside particles? The basic idea arises in diffraction—the wavelength λ of the probe, a measure of the size of the probe, must be about the size of the feature studied for us to be able to see an effect. The de Broglie relation, $p = \frac{h}{\lambda}$, allows us to relate the particle momentum to a wavelength. The relativistic energy expression

$$E = (p^2c^2 + m^2c^4)^{1/2} \sim pc \ (p >> mc)$$

then means that to see a small feature of size d, $p = \frac{h}{d}$ and so $E \sim \frac{pc}{d}$. This means that the smaller the size probed, the higher the energy needed. Physicists build accelerators to study the small subnuclear features of the universe. They must build massive detectors that provide a record of the particles passing through. So many pass through so often that interpretation is only possible when powerful computers are harnessed. Fig. 5 (above) shows the record of a detector at CERN, the European particle physics research laboratory.

The current understanding of the subatomic realm is shown in Fig. 6 (purloined from the CERN website).

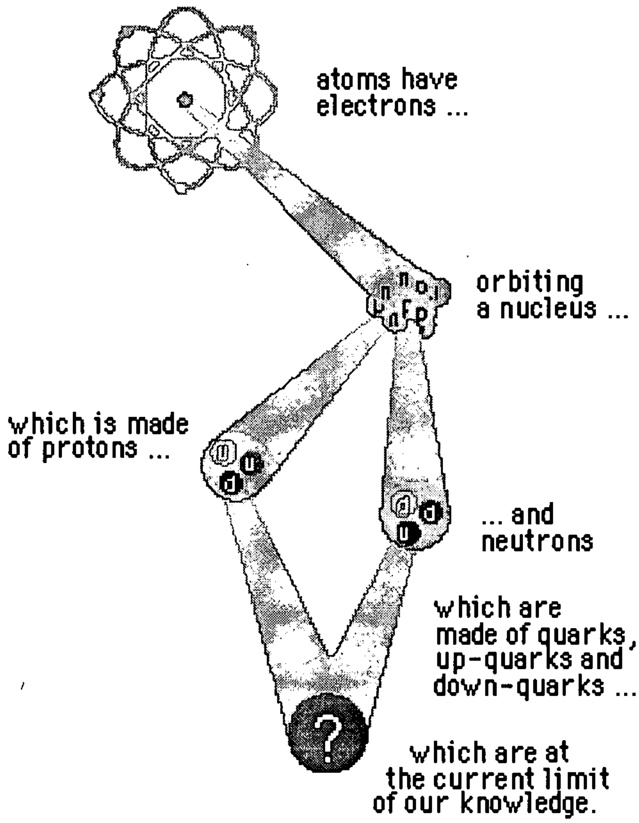


Fig. 6 The limits of current knowledge of the subatomic realm. The quarks are colored (see the CPEP particles chart).

My group's intention throughout has been to let the students themselves lead us into an understanding of their own ideas about quantization and the interaction of light and matter through interviews and surveys based on the interviews. We think we know things, but we have little conception of how our students view these matters. To be able to teach them, we need to be able to reach them where they are.

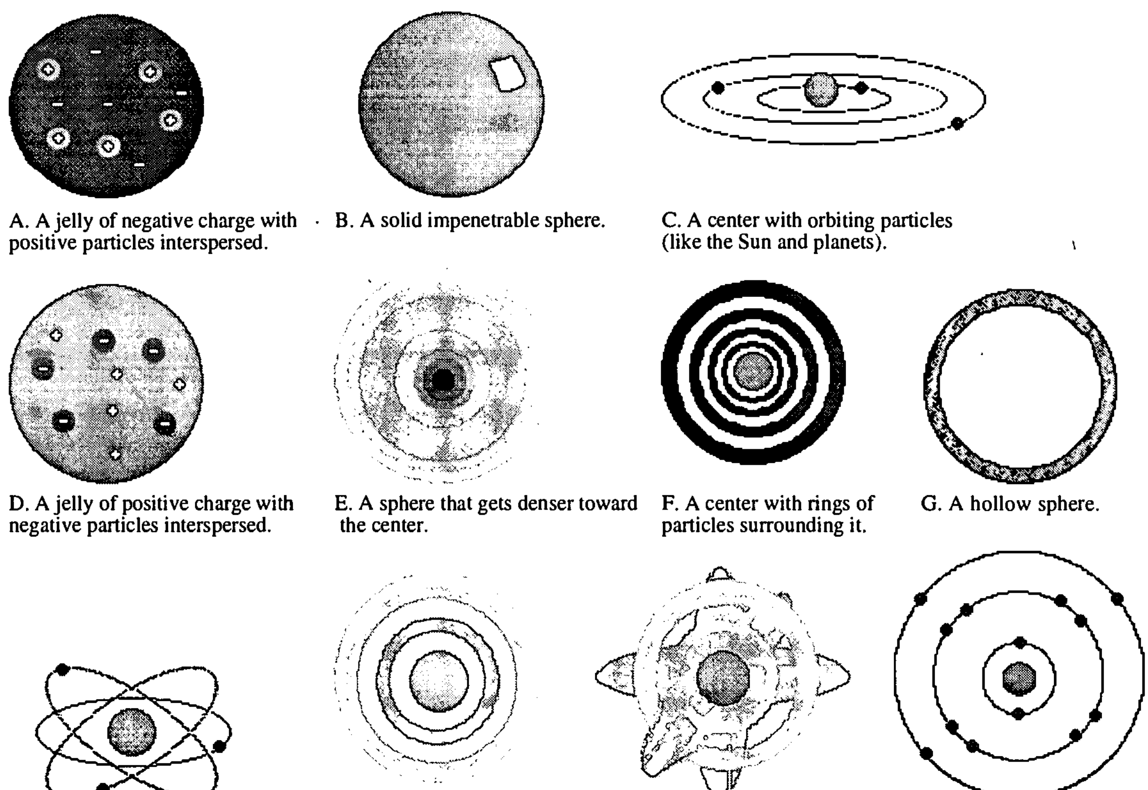
Why should we be interested? We have three basic reasons: 1. We've taught students these topics for many years, and don't really know what the students as a group are thinking, either before or after we have taught them. We'd like to know more so we can be better teachers. 2. Most people fear what they do not know, and make their lack of knowledge into a shield. Then they can be led by media misunderstandings. Remove the mystery, remove the fear. 3. Quantization is connected to all these ideas, and one can say without exaggeration that quantization *is* the physics of the twentieth century.

The new book *Physics in a New Era: An Overview* presents many areas of physics that are dependent on the understanding of quantization and related phenomena.[14] Appendix 2 contains selected quotes from this book.

Exploring student views of quantization

First let us give some definitions: *Atom*: Entity having a central nucleus containing protons and neutrons forced together by the strong interaction. Electrons are also in the atom. They do not really "move" as classical particles, but are represented by wavefunctions that give the probability amplitude for the electron at all points in space. *Radioactivity*: the transformation of a nucleus into a different nucleus and simultaneous emission of energetic particles. *Radiation*: that which is radiated, emerging along radii (spokes).

Rank the following statements about atoms from **most plausible** to **least plausible**. Circle the ones you believe **correct**.



A. A jelly of negative charge with positive particles interspersed.

B. A solid impenetrable sphere.

C. A center with orbiting particles (like the Sun and planets).

D. A jelly of positive charge with negative particles interspersed.

E. A sphere that gets denser toward the center.

F. A center with rings of particles surrounding it.

G. A hollow sphere.

H. A center with particles going around with orbits canted.

I. A charged center with places other charged particles are most probably located.

J. A charged center with spheres and projections indicating where other charged particles are most probably located.

K. A charged sphere surrounded by charged particles at symmetric locations.

Most plausible 1. ___ 2. ___ 3. ___ 4. ___ 5. ___ 6. ___ 7. ___ 8. ___ 9. ___ 10. ___ 11. ___ Least plausible

Fig. 7. Models of the atom ranking task.

One problem with interviews is that the students have to speak and are unused to doing so as they think. We have had quite some difficulty in persuading students to give us their continuing thoughts as they do their thinking. What could we do? The answer we've found: Use ranking tasks! David Torick, a graduate student in education working with me on the radioactivity project had seen the ranking task book by Heiggelke, Maloney, and O'Kuma,[15] and was inspired to try this technique in interviews. I was skeptical that it would be useful, but we tried it and found that having the task to talk about made students much more garrulous. We have been using these ranking tasks since.

One example of these tasks is illustrated in Fig. 7 above. It asks for students to rank the models of the atom shown from most plausible to least plausible. Table 2 shows a physicist's ranking of the plausibility of these models.

Table 2: Ordering of the pictures of models of the atom, according to a physicist.

Most plausible
J. This reflects the probability interpretation and shows where the electrons most probably are.
I. Again, the idea of probability is there.
H. At least there's a nucleus. A classic (?) textbook illustration.
C. At least there's a nucleus, but why should the electrons move in a "planetary" plane?
K. At least there's a nucleus. A classic (?) textbook illustration in chemistry texts.
A, D. The Thomson "plum pudding" model that led Rutherford's group to do their experiment.
F. Why rings?
E. Why relatively continuous density gradient?
B. The original model of Democritus. Not too useful.
G. Ridiculous.
Least plausible

We have done around thirty in-depth interviews examining the ideas students have about the characteristics of light and the interaction of light and matter. After these interviews of students and faculty from a number of different college physics courses, we created a survey based on the students' statements in the interviews, and, finally, interviewed a small number of students who had taken the survey to ascertain whether they had understood the questions. The latter two steps have been iterated.

Because we initially had little idea about students' conceptual understanding in this area, and because we did not want to prejudice them by putting our words into their mouths, we planned to let their responses determine the direction of each subsequent stage of our inquiry. In particular, almost every survey item came either from specific student responses to interview questions, or from ideas implied by those responses. Some of the ideas we encountered are shown in Table 3.

Table 3: Ideas found in the interviews.

• Photons are not light. • A particle cannot be a wave. • A wave cannot be a particle. • Light is not a particle. • A photon has no size. • A photon's size is related to its wavelength. • Waves that go through slits are trimmed if their amplitude is too large. • Waves that go through slits are trimmed if their wavelength is too large. • Waves that go through slits bend at a sharp angle and then continue in a straight line. • Photons are made up of smaller particles. • Protons are made up of smaller particles. • Energy levels correspond to electron positions in atoms. • Valence electrons in atoms carry photons.

To see if other students had similar ideas to those found in the interviews, we created surveys from the interview data. The surveys provide a more efficient means than interviews for collecting data from a large number of students. The students who took our multiple choice, multiple response and Likert item survey fell into three categories: engineers, technical students, and non-science, non-engineering students. These are color-coded in the pictures shown as slanting down, straight across, and slanting up, respectively.

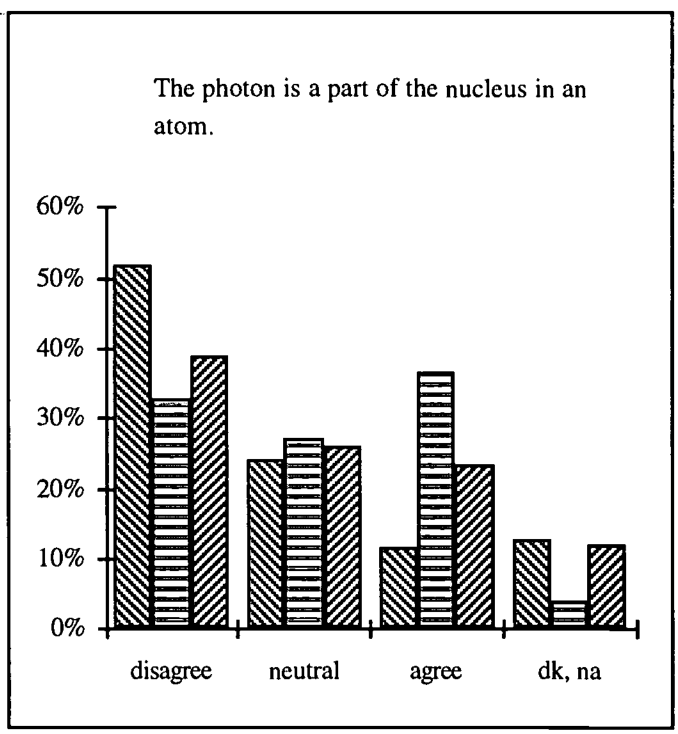


Fig. 8 Student responses to the question shown by category of student.

Surveys were constructed using two different types of items, multiple-choice/multiple-response and Likert-scale. The multiple-choice/multiple-response items dealt with mental images and photon properties. They allowed for students to make more than one choice for each item, and each included a 3-point confidence indicator. Likert-scale items are statements; students are asked to rate their level of agreement with the statements (from strongly disagree to strongly agree) on a 5-point scale. The option "don't understand" was to be chosen if the statement was somehow unclear to the student. Likert-scale items covered a wide range of topics related to photons, light, and matter.

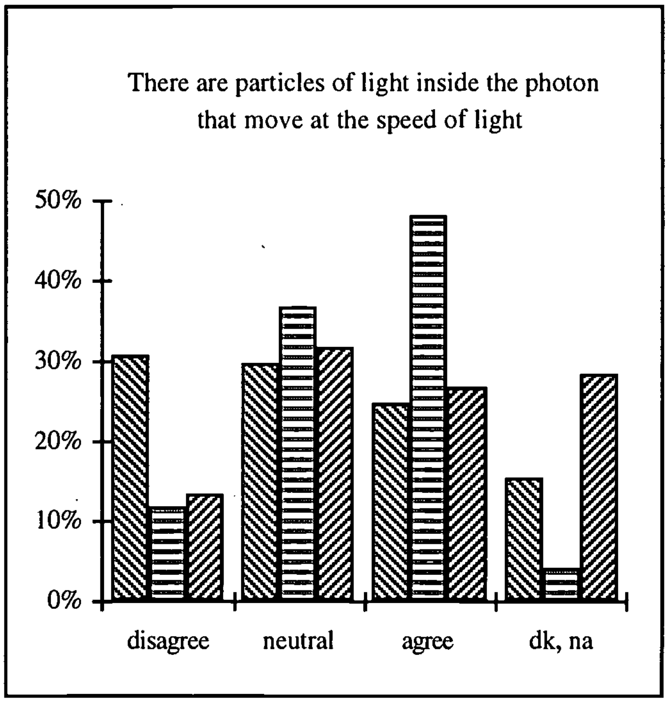


Fig. 9 Student responses to the question shown by category of student.

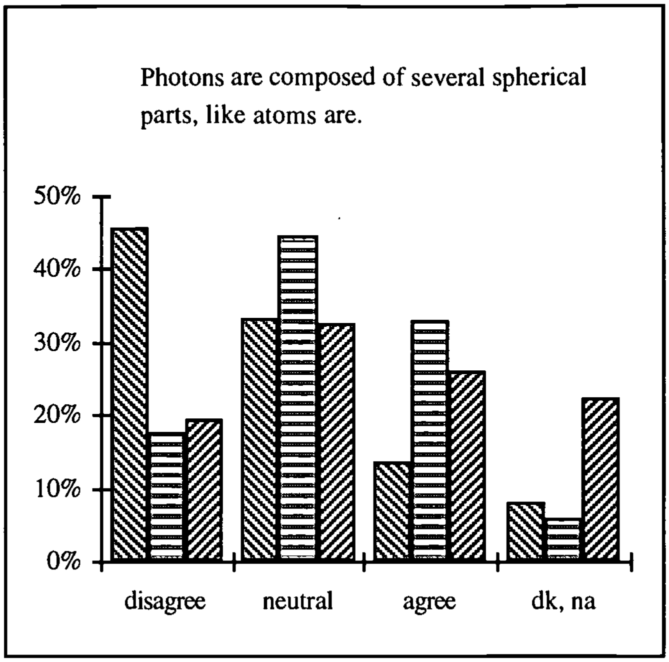


Fig. 10 Student responses to the question shown by category of student.

Various versions of our survey were given to 374 undergraduate physics students in three different categories: non-science/non-engineering majors at a large public university (120), engineering majors at the same university (170), and students in a two-year technical college at a different large public university (84). The non-science/non-engineering majors were mainly enrolled in inquiry-based courses; the others were enrolled in traditional, lecture-based courses. None of the courses or their prerequisites dealt explicitly with quantization or photons. Figs. 8, 9, and 10 show some of the responses we found.

Student interviews showed a broad range of ideas about what photons are and about what they do. Among the mental images of photons that students identify are a particle, a wave, a composite object, a "ball" or "bundle" of light, and each of the other answer choices displayed in survey multiple-choice question 1, which gave a number of choices of such images. Students also displayed a number of different ideas about a photon's properties. Many said that a photon's size is related to its wavelength or energy, that it is comparable to the size of an electron or an atom, that a photon can't "fit" through narrow slits that are smaller than its size, or that it has no size at all. Many agreed that a photon is somehow round in shape, that its speed is very large, and that it has no mass. However, about 20% did attribute mass to photons.

Two Likert-scale items showed substantially different response rates (by which we mean > 20% differences among responses) among the different kinds of students. Engineering majors were almost twice as likely as non-science/non-engineering majors to agree that "You've got to excite atoms to produce photons" (item 26, see Appendix 3). Engineers were also substantially more likely than the other groups to disagree that photons are composed of several parts (item 27BC, see Appendix 3).

The non-science/non-engineering students were much less certain about the item statements than students in the other two categories. Many of the students surveyed did not have robust ideas about photons or quantization at all. This can be seen by the frequency with which options "neutral" and "don't know" were chosen on the Likert-scale items, especially by non-science/non-engineering students; in fact, they chose the "don't know" option more frequently than the other groups on every one of the 66 Likert-scale items. These responses were quite frequent. More striking are indications that many students who had no well-developed ideas about the photon generated ideas spontaneously when presented with either a question or options.

To illustrate some of the ideas we found in the interviews on this topic, we include brief excerpts from interviews with "Dan" and "Abe." Dan believes atoms gain energy from both accepting and emitting a photon.

I: Okay. The blue doesn't quite ... The violet line produced by the mercury isn't quite in the band of the blue filter, it's probably on the edges or something. So, do you think that atoms can take and interact with light?
Dan: The electron stores photons.
I: Okay, so the electron stores photons.
Dan: Yeah. Somehow. I, I don't know what I want to say. (laughs)
I: Go ahead.
Dan: I want to say in a spark, you'd see a light.
I: Right.
Dan: If you see something sparking, that's electrons traveling. I want to say they give off a photon at that point. You'd see that light.
I: Okay.
Dan: I don't know if that's right.
I: Okay. So, after this electron gives off this photon, does the electron have more or less energy? Or does energy stay the same?
Dan: I'm gonna say the energy stays the same.
I: Why?
Dan: I think the electron's just a carrier. I don't know. I'm not gonna say.

Abe has described "good physics," but probing reveals that he thinks that bonds weaken as photons are emitted or absorbed (much as a metal weakens if it is repeatedly bent). Abe further believes that white light is "just how light comes."

I: [Do] you think an atom changes when it gives off light?
Abe: Yeah. Like I said, I think it tries to get back to its original state. When electrons are added to it, it tries to go back to the state it was before. But, you know, it keeps throwing off the energy as light. I think eventually, it would weaken whatever bond it had to the other atoms.
I: Why do you think that?
Abe: Because you know, it's energy and electrons are being added to it and being taken away, in this process of back and forth, and I think it weakens it to the point where it's not going to bond to another atom.

It appears that students have very diverse views about what photons are and what they do. This is apparent in the interviews and in the survey responses. (See Appendix 3 for a survey version.) Many think that a photon *contains* particles of light. Many fail to recognize that photons are massless. About twice as many students believe that a light wave produces photons as it travels as do not. The numbers and kinds of mental images of photons are consistent with the results of Mashhadi and Woolnough.[16]

Everyone (including experts) who contemplates light quanta depends heavily on a concrete mental model. Despite existence of the idea of light as a particle, the photon, and common references to photons in the popular media, most students lack real knowledge of what this word means. More detail on our work is to be found in the paper submitted for the MSaTERS Proceedings distributed at the meeting.[17]

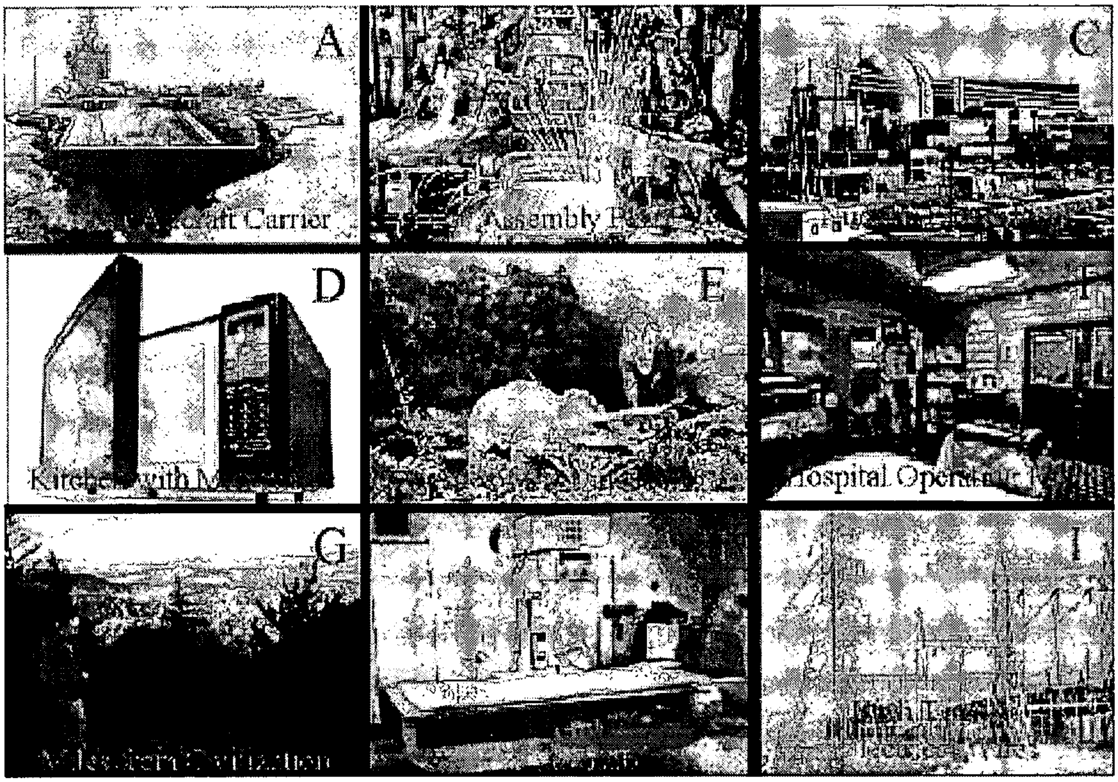
Exploring student views of radioactivity

In surveys and over 30 interviews, we have probed ideas about radiation and radioactivity held by preservice teachers. Past research[18, 19] has shown that students confuse contamination and irradiation, and that their model of half-life includes halving the mass and volume of the decaying substance. In addition, Prather has identified a valence electron model of radioactivity, the idea that the atomic electrons are responsible for the decay.[20] We have encountered these among many other ideas.

For example, many students believe that nothing (in particular, themselves and the interviewers) can be radioactive unless it is exposed to radioactivity; students often do not recognize which information they need to answer questions; many students misuse information on mass, mean life, half-life, and decay rate; many seem to think that machines make radioactivity and that no radioactivity existed until recent times.

As in the project discussed in Sec. V, ranking task interview questions were used to elicit interviewees' natural ideas about radioactivity rather than provoking a memorized response.[15] We have found in some simple ranking tasks (Fig. 11) that students, almost to a person, are unable to recognize environments representing the greatest danger to health from radioactivity. In still others, the perceived danger from radiation depends on the "more is more" idea that the greater the number of radioactive atoms present, the greater the health hazard (regardless of the activity, *i.e.*, independent of the decay rate). Our interview subjects, with little scientific background, have shown a predisposition to identify human artifice and technology as the sole sources of radioactivity and contamination.

Shown on the sheet are nine (9) different locations. All of them except the dinosaur location can be considered as present day.



Rank these situations, from greatest to least, on the basis of the amount of radioactivity you would be exposed to if you where at that location.

Greatest 1____ 2____ 3____ 4____ 5____ 6____ 7____ 8____ 9____ Least

If any amount of radioactivity you would be exposed to is the same, circle those cases together. Please carefully explain your reasoning.

Fig. 11 Radioactivity source ranking task used with interviews.

The high-tension electrical wires, car assembly plant, and location far away from civilization were all selected based on responses from our original interviews. The microwave oven was chosen based on previous work showing that students have misconceptions regarding microwaves. The x-ray room and the hospital room were also selected to attempt to elicit conceptions that we hoped were similar to those found in the work done by Kaczmarek et al.,[21] who focused on medical students' conceptions of a radiographic examinations. The nuclear power plant and nuclear aircraft carrier were used to ascertain whether interviewees identify any level of radioactivity outside of the containment areas. The "age of the dinosaur" scenario was chosen to see whether they believed that radioactivity derived from human intervention or was natural.

Table 4: What about the radioactivity? A physicist's classification.

High

Age of dinosaurs (E), Far from civilization (G)

Why? Rock (granite) has substantial thorium and uranium concentrations, and these are a emitters.

May be high

Kitchen (D; microwave irrelevant), Hospital operating room (F), X-ray lab (H)

Why? Radon is radioactive. It concentrates in closed rooms unless active steps are taken (in some regions of the country).

Low

Nuclear aircraft carrier (A), Nuclear power plant (C), Auto assembly plant (B), High-tension wires (I)

Why? (A, C) Outside the shielded reactor cores, there is very low radioactivity; (B) Large building, mostly outside air, little radon; (I) Outside air, little radon

Table 5: What about the radiation? A physicist's classification.

High

Hospital operating room (F), X-ray lab (H)

Why? When the x-ray machine is on or barium is used or radioactive pellets are inserted, there is exposure to the products of radioactive decay and to the x radiation.

Low

Nuclear aircraft carrier (A), Nuclear power plant (C), Auto assembly plant (B), High-tension wires (I), Age of dinosaurs (E), Far from civilization (G), Kitchen (D)

Why? All have exposure to cosmic rays, all are equally exposed. (The microwave radiation is nonionizing!)

After you examine the task and choose your answer, look at Table 4, which shows a physicist's ranking of the sites with respect to radioactivity (see definition above). Table 5 shows the physicist's ranking with respect to radiation. Table 6 shows the interviewees ranking summary.

Table 6: Results of ranking task on sources

Item	Averaged Ranking	Standard Deviation
H. X-ray lab	2.3	1.4
C. Nuclear power plant	2.7	2.6
I. High-tension electrical wires	4.2	2.0
D. Kitchen with microwave	4.3	2.5
A. Nuclear aircraft carrier	4.4	2.4
F. Hospital operating room	5.1	1.4
B. Car assembly plant	5.7	0.71
E. Age of dinosaurs	7.1	2.3
G. Far away from civilization	7.9	0.93

We present here some student comments with respect to the levels of radioactivity at the specific sites shown in Fig. 11.

Aircraft carrier:

I do not know that much about some of the things, but the nuclear power plant, and the nuclear aircraft carrier, would to me, be great sources of radioactivity.

Assembly plant:

The car assembly plant, because, again, just seeing all those electrical waves. And I think that equates to radioactivity, too.

There is machinery there, so that just make so that just makes me think that that could be more radioactive than being away from civilization or age of the dinosaurs.

Nuclear power station:

The nuclear power plant I think will be next, because again, the way I think there is just a lot not known about the nuclear, and I guess I just do not understand when I hear it on the news, about the nuclear power plant and how it can affect you. ... So I think that there is more to it than what we can see, and nuclear just sounds like a terrifying word to me.

High tension wires:

Well, the first thought that comes to my mind is, supposedly those people who live near high-tension electrical wire, that they are receiving doses of radiation.

I don't think you would be able to build houses right next to them or whatever if they did. I think there would be more of a concern if they had a lot.

Age of dinosaurs:

I am going to say E is the least, without thinking much. Because, as far as I understand, most of the radioactivity around today is because we have generated it in our technology.

E the least, because there was not man on the planet making extra, generating, making nuclear power plants and stuff.

Well, I probably would go with the past day as the least amount of radioactivity. Just because, well, I don't think there is any electricity around back then ... [Next] I would go with miles from civilization, 'cause when I think of radioactivity, I think that of electronics and power lines and appliances and that kind of thing.

Because I was thinking that like plutonium and uranium, I think that they occur naturally in nature, they can be found there. And I just think that now we are probably were those things are because we use them for different things, like the nuclear power plant, so I think that there would be less in the Earth.

I think the least would be right here, at the age of the dinosaurs. Because I just think a lot of that area was just more natural it was not touched by humans.

I think that after this time period when the dinosaurs lived in, humans began to contaminate the land a little bit more. And so when I see this human being ... something just triggers in my mind, like someone messed with this environment.

The age of the dinosaurs would be closer to the birth of the Earth ... But anything that did have half-lives that have gone through their half-lives have already started to deteriorate by this point,.the miles from civilization. Whereas here, not as many things would have deteriorated.

Hospital operating room:

I would say hospital operating room, next because I feel like, I always see the warning signs, like warning radiation. Like maybe there is stuff that is used that has radiation in it.

I don't think they have, I mean, I am not really sure how they work, is it radiation that is even an issue with them. And if it is, it is that not different than radioactivity.

Far from civilization:

I would say that G, miles from civilization, may have some but I don't think it is going to be very strong. 'Cause I am not sure, but I think uranium occurs naturally, and maybe there is some just given off naturally from the Earth.

I know that there is natural radioactivity occurring, like in certain, probably, rocks and minerals and things. And those things are going to be present now and when the dinosaurs are around, too.

Just because there is not a lot of stuff that man generates, same theory as the dinosaur thing.

X-ray lab:

I am thinking this x-ray lab, because really what I heard more so when I go to a doctor and get a checkup. Or I have had x rays before and they always put, this something over you to cover vital organs or whatever. And so I just think that that is the most.

You always have to wear lead gear when you are getting an x ray, I would guess H first. ... No lead things no nothing, I would think that this is probably the greatest, the x ray.

Microwave oven:

Um. Well, I assume some radiation is being emitted from the microwave oven, which is why you're not supposed to stand in front of it.

The microwave oven does stuff that I cannot even begin to guess at. If you were to stick a cat in the microwave, you better not be expecting it to come back out alive.

Could be things wrong with my kids.

[T]he microwave, I think, will be next, because again it's, like, the radioactivity to warm up food and stuff like that [sic]. And to be honest with you, I don't know if some of those waves are going into that food when I warm it up. And I just think that anything manmade can have a negative effect to humans. That we can not see right up front, but maybe 10 to 15 years down the line may develop into cancer or birth defects.

These quotes were not uncommon. Figures 12 and 13 show just how dubious students were about microwaves on the surveys given on quantization.

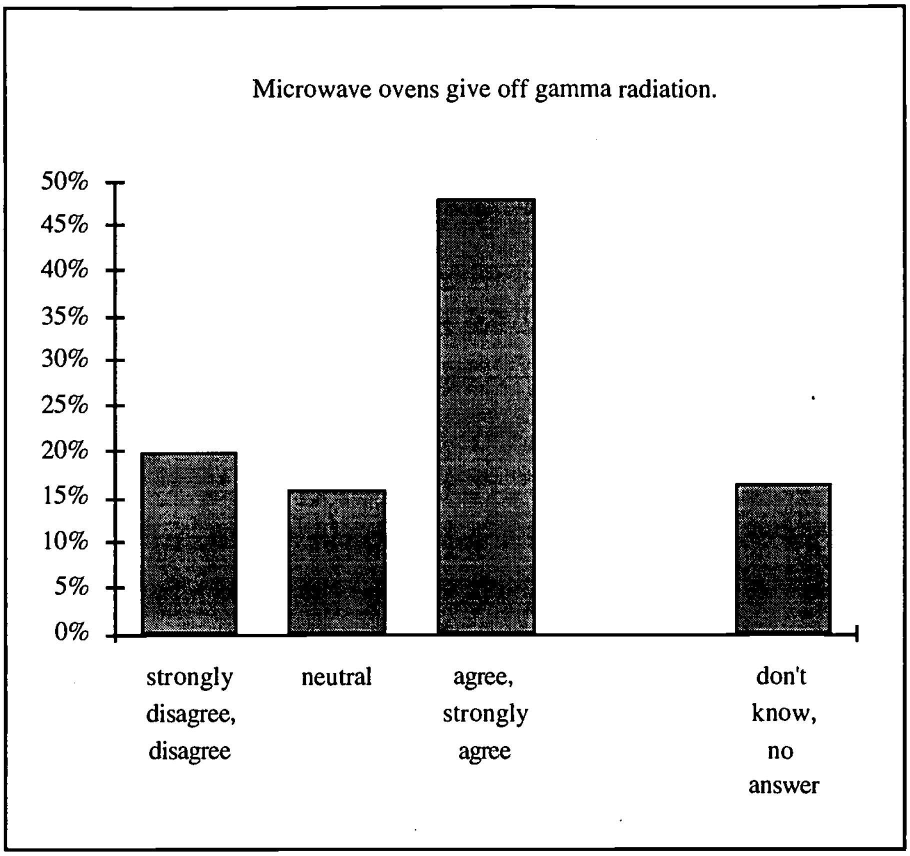


Fig. 12 Students believe microwaves give off γ radiation.

Overall, our study showed that student ideas about radioactivity were pretty unscientific and conventionally muddled. Many students cited their own teachers as the source of their incorrect ideas, while many cited mass media. Many students unable to recognize environments representing the radioactivity. Many perceived danger from radiation that depends on the "more is more" idea that the greater the number of radioactive atoms present, the greater the health hazard. Students often do not recognize which information they need to answer questions. Many students misuse information on mass, mean life, half-life, and decay rate. Students also believe that the greater the number of radioactive atoms present, the greater the health hazard (regardless of the activity, *i.e.*, independent of the decay rate). Finally, human artifice and technology are seen as the sole sources of radioactivity and contamination. These student ideas are discussed in greater detail in Refs. 22 and 23.

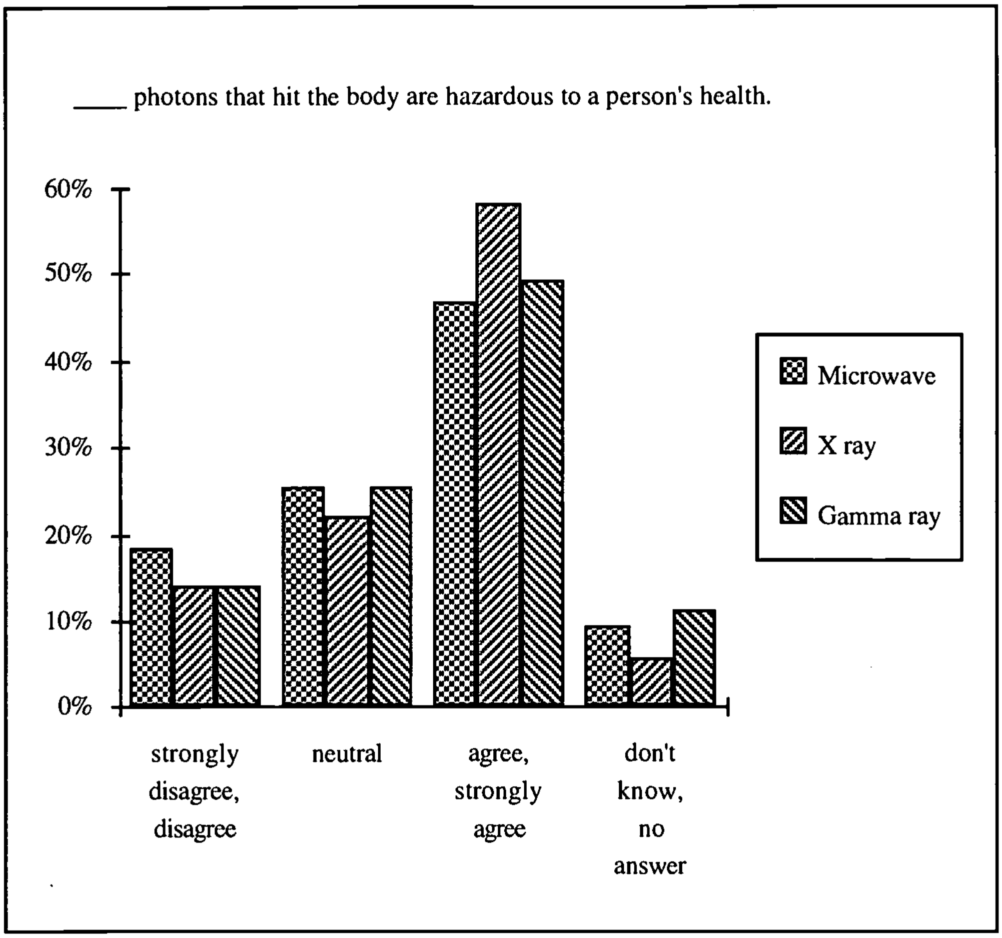


Fig. 13 Students generally believe all sorts of the radiation that they think microwaves give off are harmful.

A major goal of our project was to see if we could create instructional materials that addressed the preexisting student ideas. We have so far written four modules. Module 1, detection, treats the Geiger-Müller counter, has students do a radioactive balloon experiment, attempts to have them define ionizing radiation, and introduces the ideas of background radiation, count rate, and uncertainty. Module 2, measurement, has students measuring the activity of sources of radiation—which ones are more active?, has them decide how to say whether something is radioactive, has students investigate whether irradiated objects are radioactive, and treats the difference between contamination and irradiation. Module 3, decay, has students (as is often done) use dice to simulate radioactive decay—but we added an unconventional twist to make sure they know that the decayed "nuclei" are not lost, has students see what N(t) and activity are, and how they are connected, shows them decay curves, explores the meaning of "exponential," the relation of lifetime and decay rate, and half-life. Module 4, shielding, is the most conventional, dealing with absorbers, comparing absorption of α, β, and γ, and investigating the effect of increasing absorber thickness. These are freely available,[24] and we would appreciate comments on them.

An interesting point is that we have used our research to ask students questions that explore their preconceptions. An series of examples, modeled on those found in *Physics by Inquiry*,[25] follows:

1. Two other students are having a discussion. Explain whether you agree with student 1, student 2, both students, or neither one.

> *Student 1*: Our background is 0.20 counts per second. The object we measured with the Geiger counter registers 105 counts per second. The object is a source of ionizing radiation.
> *Student 2*: You can't say that. The greater the count rate, the faster the object decays. It's decaying away so fast it can not be a source of ionizing radiation.

2. Consider the following debate between two students regarding the fruit on the radioactive plate:

> *Student 1*: We saw that the fruit was absorbing the radiation from the object. I think radiation trapped inside the fruit will cause the fruit to become radioactive.
> *Student 2*: I disagree. I don't think that the radiation given off is radioactive. I think the object that produces the radiation is radioactive. Some of the radioactive object would have to get onto or inside of the fruit to cause the fruit to become radioactive.

3. Consider the following colloquy among three students regarding the effect of the half-life of a sample of a radioactive material, carbon-14. The half-life of carbon-14 is measured as approximately 5700 years.

> *Student 1*: After a thousand decays, half of your little pile of carbon-14 there is going to be gone. There is still going to be a thousand decays coming from the half the substance that's left.
> *Student 2*: For carbon-14, 5700 years is the half-life. In order to insure it will be all gone, I would say you would have to have it for a time double the half-life. Because if only half the nuclei decay in that amount of time, who is to say that one atom you have is in the half that is going to decay or not decay?
> *Student 3*: I picture the carbon-14 as a glowy thing. I have the glowy thing, which is just the intensity of the radiation is decreasing, and then I have the half-life, which tells me half of the material disappears after a given unit of time.

4. Two students are arguing about detection of radiation as the source is moved relative to the detector. Explain which student you agree with and why.

> *Student 1*: When the source is moved farther away, there is a beam coming toward the Geiger counter and the count rate remains the same, no matter how far away the source is moved.
> *Student 2*: The count rate decreases when the source is moved farther away from the Geiger counter. Since the particles are emitted in all directions, fewer of them hit the window of the Geiger counter.

These questions are all followed, as in *Physics by Inquiry*, by the question: Do you agree or disagree with the students' comments. Explain your reasoning.

Conclusions

It is worthwhile for citizens to know what and why we believe there are tiny particles making up everything in the world. The process of science, the way science uncovers this understanding could help lead to lesser fear of the unknown and less mythmaking.

We are finding out about more about the initial states of students' ideas about the basic building blocks of matter and their perception of how these interact. The discrepancies between student "initial states" and expert thinking will, we hope, give us clues as to how to help students change their organizational principles.

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Appendix 1: Ideas about science from Crank.net

From the website http://www.cropcircleresearch.com/ quoted at CRANK.net.

"The Independent Research Centre for Unexplained Phenomena was founded in 1993 by Paul Vigay, after a number of personal experiences and four years of extensive research into the continuing crop circle enigma. Paul was previously a UFO and paranormal investigator, but became interested in crop circles in 1989 when he discovered anomalous electrical effects in and around crop formations. After four years it became increasingly apparent that there was a real and genuine mystery to the subject. Not only have strange aerial anomalies (UFOs) been linked with crop formations, but many people and objects have been affected by their influence -- either positively or negatively. Another thing, which has become increasingly obvious during the last couple of years is the seemingly paranoid attempts by some skeptics and hoaxers to try to debunk the subject in the eyes of the general public."

From the website http://www.haberco.com/ns/ns5.html found at CRANK.net.

"Haber's new model of the atom is that the nucleus is an oscillating skin, symbolically like that of a basketball. The incredibly quick oscillations of the skin create electrons that radiate outward and anti-electrons that radiate inward. He refers to the skin itself as the neutron shell. Done away with is the proton, which Haber claims has only created confusion in the world of Quantum Physics leading to a 'particle zoo,' the uncontrolled labeling of particles that don't exist to create other particles that don't exist, and such concepts as renormalization, in which both sides of a mathematical formula are divided by zero; unthinkable even to 9th grade algebra students. Haber describes the fleeting particles that are created in bubble chambers and particle accelerators as being fluke events and not actual particles."

From the website http://www.searleffect.com/ found at CRANK.net.

"An effect based on magnetic fields that generates a continual motion of magnetized rollers around magnetized rings producing electric energy and, under certain conditions, an anti-gravity effect that can be used for propulsion. Side-effects include negative ionization of surrounding air and a cooling of temperature around the device when in operation. ... Prof. John Searl is the ONLY man in history to have built and flown an antigravity device called a levity disc, now called Inverse-G-Vehicle."

From the website http://www.stormloader.com/joshua/redmercury.html found at CRANK.net.

"For years, there have been rumors, almost in the urban legend category, that the Soviet Union had developed some mysterious substance called 'red mercury' that can be used in nuclear weapons construction, and that this 'red mercury' may be available on the black market for 1000- 2000 per kilo.

Rumors have touted it as being able to just about anything including: making stealth aircraft stealthier, infrared sensors more sensitive, counterfeits harder to detect, and fission and fusion bombs smaller and easier to construct. It may be radioactive or not. It may be the densest material or it may not. ... I would wager that red mercury may be useful for much more than destruction. What can kill can cure, eh? Anyway, the truth makes free.

HOW TO TURN QUICKSILVER INTO A WATER WITHOUT MIXING ANYTHING WITH IT

"

Appendix 2: Quotes from *Physics in a New Era: An Overview*, National Research Council, 2001

The following are disconnected quotes from various sections of this book illustrating how deeply contemporary physics is involved with quantum mechanics, the nanoscale, and the microworld.

"An atom or molecule in such a light field is really no longer an atom or a collection of atoms, but rather a new regime of matter, with the electrons, atomic nuclei, and light field having equal roles in determining the structure and behavior."

"Many structures in nature are well organized on the nanoscale. For example, a seashell has a complex interleaved structure with exceptional strength yet low mass. ... So-called diblock copolymers are a beautiful example from chemistry: polymer blends that give perfectly organized and highly controlled structures on the nanoscale."

"The study of nanoscale electronic devices began to blossom in the last decade and a half. It is now possible to fabricate devices that are so tiny that the charging energy needed to add or remove a single electron becomes easily observable. In some cases even the spacing of individual electron energy levels is large enough to be discernable, making these devices analogous to artificial atoms."

"We are in the midst of an exciting revolution in the ability to observe and manipulate material at the quantum level. The next few decades are certain to lead to new insights into the strange world of quantum physics and to dramatic advances in technology, as the field of quantum engineering is developed."

Appendix 3: Version B of the survey

##

Give the best answer(s) to the multiple choice questions.

##

1. What are the images that come to mind when you hear the word PHOTON?

(Circle all that apply.)
a. a particle
b. a wave
c. a packet of energy
d a small, round, positively charged object
e. a high-energy bullet
f. quanta of electromagnetic radiation
g. an extremely small particle in an atom
h. beams of light
i. something very small
j. a ball of light
k. a disk about the size of a dime
l. rod-shaped particles
m. a ball of some kind that's always white in color
n other (please explain):______________________________

2. Which of the following physical characteristics do you MOST FREQUENTLY use to describe a photon? Circle all that apply; more than one answer could be correct.

a. wavelength
b. frequency
c. energy
d. mass
e. none of the above; photons are too "small"

If you circled (e), explain what you mean by "small."

My confidence: very certain confident not very confident

3. Which of the following BEST describes the size of a photon? Circle all that apply; more than one answer could be correct.

a. photons have no size
b. the size of an atom
c. the size of a nucleus
d. the size of an electron
e. smaller than an atomic nucleus
f. photons come in a variety of "sizes"

If you circled (f), explain what you mean by "sizes."

My confidence: very certain confident not very confident

Note: If you answered (a) to question 3, you may skip question 4 and go directly to question 5.

4. Which of the following has/have to do with the size of a photon? Circle all that apply; more than one answer could be correct.

a. energy
b. wavelength
c. mass
d. frequency
e. amplitude

My confidence: very certain confident not very confident

5. The word "quantization" refers to

a. the separation of the parts of light into their component frequencies.
b. the separation in energy levels in atoms.
c. the fact that photons can have certain energies, but not ANY energy.
d. the partitioning of photons into parts.
e. the explanation of energy levels in atoms.
f. how much energy something has internally.

Circle all that apply above; more than one answer could be correct.

My confidence: very certain confident not very confident

##

Use the scale from strongly disagree to strongly agree to respond by circling your answer on those questions asking for this rating. *Neutral* means that you neither agree nor disagree, ***Don't understand*** means that you have no idea at all what the question is about.

##

strongly disagree disagree neutral agree strongly agree don't understand

6. 1 An individual photon can have any single frequency in the spectrum.

7. A photon is much smaller than an electron.

8. Microwave ovens give off gamma ray photons.

9. Some photons can be seen by the eye, but only if there are large numbers of them.

10. An individual photon contains all the frequencies of the spectrum.

11. Photons are spherically shaped, like protons or neutrons.

12. A photon is a point. It doesn't really have a size.

13. Wiggle a charged particle and it creates photons.

14. The photon is a part of light and quantization means the separating of these parts.

15. An individual photon can have only frequencies that are in the visible region of the spectrum.

16. A light wave produces photons as it travels.

17. A photon is a few nanometers across.

18. The photon is a part of the nucleus in an atom.

19. A single photon of the right type can be seen by the eye.

20. An individual photon doesn't have a frequency, but collections of photons do.

21. Gamma ray photons that hit the body are hazardous to a person's health.

22. Smash two nuclei together so that they join and make a new nucleus. You will produce photons because the new nucleus you make will have a different rest mass than the sum of the other two rest masses.

23. If you heat metal so that it glows, it emits photons.

24. I have no idea of what "quantization" means.

25. Decent enough photographic film can detect one photon hitting it.

26. You've got to excite atoms to produce photons.

27. Photons are composed of several spherical parts, like atoms are.

28. The force between two charged objects is caused by an exchange of photons between them.

29. A photon is white light.

30. If somebody did an experiment where they were able to knock electrons out of anything using light waves, it would show that photons behave as particles.

31. Photons are not light, but can produce light.

32. When electrons change their energy levels in an atom, photons are being absorbed or emitted.

33. The photon is not real, it is only a way of thinking about light and energy.

34. A photon is a particle that carries light.

35. A photon is about the same size as a proton.

36. When you see the light coming out of a bulb, there're millions and millions of little photon particles that come out.

37. There are particles of light inside the photon that move at the speed of light.

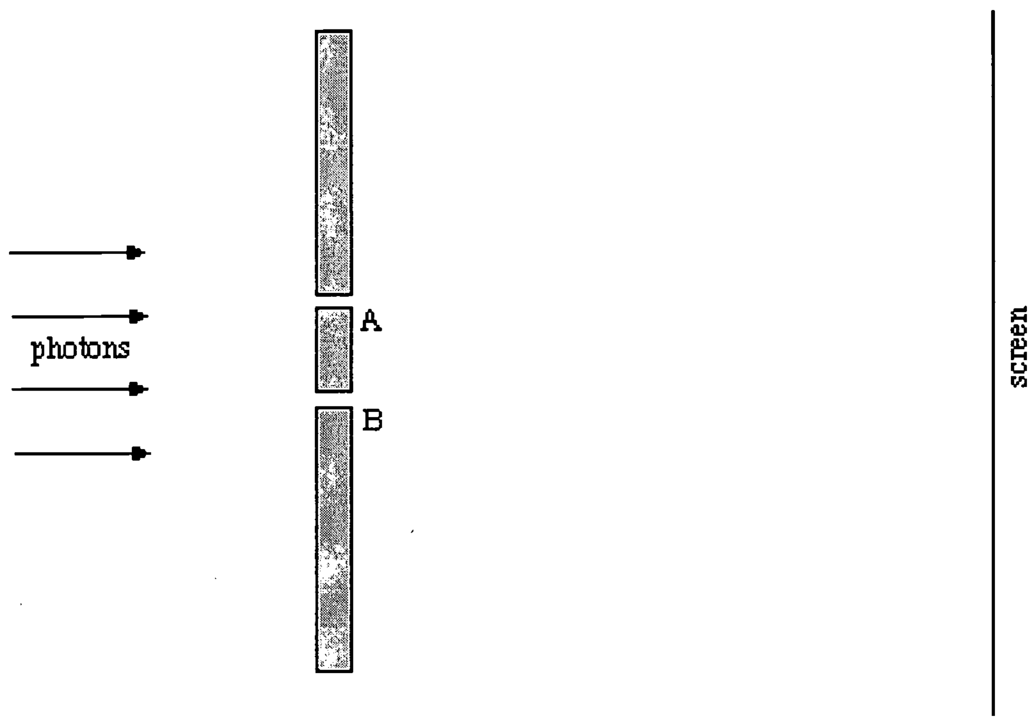
38. When a photon travels through a slit of width less than its amplitude, only part of it gets through the slit (it gets "chopped off").

39. Shadows are caused by the absence of photons, because a photon can't get through the object casting the shadow.

40. Gamma rays that hit the body are hazardous to a person's health.

41. A photon is a building block of light.

42. The reason that the electrons in atoms don't just fly off into space is because they pass photons back and forth with the nucleus.



43. Photons do funky things. If a single photon goes through a double slit (slits A and B, above), that photon actually goes through both slits A and B at the same time.

44. Microwave photons that hit the body are hazardous to a person's health.

45. When a photon travels through a slit of width less than its wavelength, only part of it gets through the slit (it gets "chopped off").

46. When the electron in a fluorescent light bulb drops from a higher to a lower state, it fluoresces as it collides with photons.

Radiation and Radioactivity: Student Ideas and Materials Development Based on Student Interviews

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Abstract

Strengthening the preparation of teachers during their college careers is a central element in improving schools. Future educators who leave a university with misunderstandings of science processes and intent as well as false "facts" have a great likelihood of perpetuating them. We attempt to prevent this by working to devise a research-based curriculum to meet the needs of preservice elementary school teachers. We have interviewed many students who plan to become elementary and high school teachers to see what information about radiation and radioactivity they "know." Ignorance is more common than accurate knowledge. We share the results of our interviews. One goal in this project is to determine if we can create inquiry-based materials on radiation and radioactivity that involve students as constructivist learners. Preliminary materials we have developed based on the information gained in these interviews will be discussed and distributed.

Introduction

Much recent research is based on the recognition that students already have ideas about physics before they ever come to class. This may be especially true of student views on radiation and radioactivity. [1-3] (We already know that much media information is biased and/or incorrect.) Because we think contemporary physics instruction should address contemporary topics and because of our interest in nuclear physics, we have investigated student views among preservice teachers enrolled in the graduate school of education at The Ohio State University.

We have conducted over thirty individual interviews focusing on radioactivity. Past research [1, 2] has shown that students confuse irradiation and contamination, and that their model of half-life includes halving the mass and volume of the decaying substance. Prather [3] identified a "valence electron model" of radioactivity employed by some students, the idea that radioactivity is determined by atomic electrons. These among many other ideas were observed. Ranking task interview questions (discussed in detail below)

[4, 5] were used to elicit interviewees' natural ideas about radioactivity rather than eliciting a memorized response.

Having learned in detail about students' ideas, we are devising curriculum related to radiation. We want to create inquiry-based materials on radiation and radioactivity that involve students as constructivist learners. Research [6, 7] shows that students taught in traditional lecture forms do not develop the understanding of physics concepts different from their initial "common sense" (mis-) conceptions we believe is necessary.

Materials and Methods

In our first round of interviews, simple questions were asked and students were encouraged to expand on their ideas. We were able to elicit conceptions through the students' explanations of existence of background radiation, whether objects have any activity at all at any time, how decay might occur. During this round of questions, we discovered interesting beliefs about what is radioactive. In order to begin to formulate a quantitative understanding, we designed ranking task questions [4, 5] for our next two rounds of interviews. In ranking tasks, students are given a set of materials, diagrams, or possibilities, and asked to rank them in some order. Student choices reflect their underlying thinking about the subject of the questions.

In our final two sets of interviews, we used ranking task activities that depicted nine different situations for the students to rank from highest to lowest based on exposure to radioactivity, examined the effect of withholding information on students perception of radioactivity, and looked at student ideas of the difference between original and decay products. We will now discuss each of these instruments in more detail.

Radioactive sources

There were three phases of interviews in an attempt to find student conceptions regarding radioactive sources. The interviewees were asked if there was any radioactivity in the interview room (a typical conference room at the university). After this, the interviewees were shown a Geiger-Müller counter and asked if they understood its function. If the interviewees were unaware of its function, we described its use in detecting radioactive decay products. We chose not to explain the process, but only to describe how the instrument works. The interviewees were then asked if they thought that it would show any readings if it was turned on in the room. This background radiation question was chosen to eliminate any bias from the testing instrument. After the interviewees had given a prediction, we turned on the (audible) counter. Randomly-occurring tones signified detection of radioactive decay products. The interviewees were then asked to explain where the detected radioactivity may have been coming from. We report on these findings below.

Interviews on Radioactive Sources

This first round of interviews involved twelve preservice teachers. Eleven of these were part of a science, math, and technology education program for secondary education. The other person was in a preservice elementary school program. All of the interviewees had received a bachelor's degree in some field and were preparing for state certification in teaching.

These interviewees were split in their response to whether or not the detector sensed any radioactivity. The interviewees who were able to predict that it would detect radioactivity believed the sources were ourselves and/or the cosmic radiation. Students who did not think that the detector would detect a decay provided interesting insights into their beliefs when forced to explain why it clicked. Some students believed it was due to the lights in the room, nearby high-tension wires, or machinery in the building. A phone study conducted by Mancl et al. [8] showed that fewer than 25% of college graduates believed that radiation exposure can occur from building bricks. During these early interviews, students also pointed to minerals and rocks as sources of radioactivity. This identification surfaced during interviewee explanations to other questions rather than as a result of our suggestions. One student believed that living things were not radioactive, and when asked what inanimate objects were radioactive, the student replied, "I think of, like, minerals. Minerals could be radioactive things. I think of rocks or metal."

Ranking Task Activity on Radioactive Sources

We chose to use a ranking task question in subsequent interviews to attempt to elicit more clearly what students naturally believed. After analyzing our first round of interviews, it was obvious that students had ideas that were substantially different than current scientific understanding supports. We developed the ranking task question using some of these conceptions, as well as other concepts we were hoping to verify. A modified version of the question is shown in Fig. 1. For clarity, the colored pictures have been replaced by words and the ranking sheet has been omitted. The general form of this sheet is similar to O'Kuma et al.'s [5] ranking task exercises.

A. Nuclear aircraft carrier	B. Car assembly plant	C. Nuclear power plant
D. Kitchen with microwave	E. Age of the dinosaurs	F. Hospital operating room
G. Far away from civilization	H. X-ray lab	I. High-tension Electrical wires

Fig. 1 A situation depicting a ranking task for sources of radioactivity at 9 different locations. Students were asked to rank the locations in terms of hazards. The text summarizes the locations shown.

The high-tension electrical wires, car assembly plant, and location far away from civilization were all selected based on responses from our original interviews. The microwave oven was chosen based on previous work showing that students have misconceptions regarding microwaves. The x-ray room and the hospital room were also selected to attempt to elicit conceptions that we hoped were similar to those found in the work done by Kaczmarek et al. [9], who focused on medical students' conceptions of a radiographic examinations. The nuclear power plant and nuclear aircraft carrier were used to ascertain whether interviewees identify any level of radioactivity outside of the containment areas. The "age of the dinosaur" scenario was chosen to see whether they believed that radioactivity derived from human intervention or was natural.

Table 1 Results of ranking task on sources

Item	Averaged Ranking	Standard Deviation
H. X-ray lab	2.3	1.4
C. Nuclear power plant	2.7	2.6
I. High-tension electrical wires	4.2	2.0
D. Kitchen with microwave	4.3	2.5
A. Nuclear aircraft carrier	4.4	2.4
F. Hospital operating room	5.1	1.4
B. Car assembly plant	5.7	0.71
E. Age of dinosaurs	7.1	2.3
G. Far away from civilization	7.9	0.93

The ranking task activity was able to elicit some common student conceptions regarding the greatest sources of radioactivity. Table 1 shows the average of their responses (N = 10). If an item is ranked most radioactive it receives a score of one, the second most radioactive receives a score of two, etc. Any item considered the same as another is scored as the smaller of the two numbers (the higher source). This ranking may well cause some of the averages to be weighted to a lower number.

The sample size for these data is 10. Given this small number, we do not suggest that they represent general students. However, students seemed to give common answers and reasoning. Only two students did *not* rank the nuclear power plant among the top three in radioactivity. We note that these students described their location to be in the power plant parking lot even as they ranked the plant high on the amount of radioactivity detected. The x-ray lab was never ranked below fifth for exposure to *radioactivity*. Millar's study [10] of high school students in the United Kingdom showed that they had great difficulty differentiating between radiation and radioactive material, so we should not have been surprised that the x-ray lab was ranked so highly.

As the interviewees worked on the ranking task, we would continually prompt them to think aloud and explain their reasoning. An interviewee who ranked the high-tension power lines as low in radioactivity reasoned: "I don't think you would be able to build houses right next to them or whatever if they did. I think there would be more of a concern if they had a lot" [of radioactivity]. Interestingly, this student ranked the nuclear power plant and the nuclear aircraft carrier as the top two situations for exposure to radioactivity. This student believed that society would protect her home from radioactivity; however, she was not comfortable with transferring this trust to nuclear reactor safety. In fact, only one interviewee ranked the nuclear power plant as having very little threat. "I am going to say for the least: I would say the nuclear power plant because I know that they keep the radioactive stuff, the isotopes the radioactive materials under water. And I know the water is safe enough, at least the one that I went to." (This student had taken a tour of a nuclear power research reactor at The Ohio State University. It is worth noting that other interviewees went on this same tour.) Other students were also uncomfortable ranking the nuclear power plant as low exposure to radioactivity. "I am sure they have a lot of safety measures against, well, for everything, safety in general, if something went wrong in a nuclear power plant. Even though ... they said if anything went wrong we would still be okay. Just it still being a fairly new way of power, I don't know."

Interviewees were also effective in expressing their reason for ranking areas low in radioactivity. Four of the interviewees believed that the locations far away from civilization and the age of the dinosaur would be very low in radioactivity because we, as humans, had not affected it. "I think the least would be right here, at the age of the dinosaurs. Because, I just think a lot of that area was just more natural, it was not touched by humans or I am going to say the least with out thinking much. Because, as far as I understand, most of the radioactivity around today is because we have generated it in our technology." By examining the least radioactive pictures, we note that the location far away from civilization was only ranked above eight twice, while the age of the dinosaurs was ranked above eight three times.

Rankings of radioactive samples

Many book sections on nuclear physics focus on calculating half-life, mean life, and the decay rate. We developed several different ranking task interview questions to determine what students intuitively believed about the relationship between these factors and radioactivity. We also attempted to uncover students' beliefs regarding what can affect the radioactivity of samples.

In our initial interviews, it became apparent that the students believed that radioactivity was context-specific. For example, during our first interviews, several students asserted that atoms on the surface were more likely to decay than atoms inside a substance. This view motivated us to develop new questions for a second round of interviews. These questions exposed student beliefs on the effects of temperature, element, or quantity, and the state of matter of the sample. In our final round of these interviews, we created four ranking task questions that allowed us to view the interviewees' attempts to utilize lifetime or decay rate information in comparing the radioactivity of several samples.

The first set of interviews posed several questions on half-life and what remained after one half-life, originally intended to reproduce previous work [1, 3, 8, 10] that had shown that students often believe that half-life relates means halving the mass and volume. Such views were indeed found. Although we were originally seeking to understand what students believed happens after one half-life, we found some interesting conceptions after deeper probing. One student believed that an element would have a greater radioactivity if it was spread out (in pitchblende) versus being in one homogeneous substance, "Based on … the surface area; with it being scattered, you have more exposure rather than a chunk." Another student used similar reasoning in explaining why more atoms would decay on the surface than in the center of the sample: "if it is losing something, it is easier for this to lose something to the environment." A third student believed that atoms in the center of the sample would decay quicker because "when it radiates, particle, usually, those particles have lots of energy. And I am thinking, that, since they do have a lot of energy, if they hit another atom, they could somehow disturb that atom, especially if that atom is already unstable. They might, like, kind of, have an influence on them, make it more likely to emit something itself, when it collides with a high active particle." Most students believed that there were outside factors that influence radioactivity. As we reviewed our results, we were happily surprised that half of the students believed that state of matter would have no effect. Of those students who did believe that state of matter did affect decay exhibited the effects of media, "when they have ... explosions at Chernobyl and stuff, the threat is ... when it is out in the gas." Students consistently believed that temperature affects radioactivity. All but one of the students believed that radioactivity increased as temperature went up. "I would think that when ... it is hot it is more radioactive. Just because, like, hot temperature makes things move around more. Like in air when the air is hot the molecules move around more. And, um, so I think that it would give off more radioactivity if it was hotter."

Our third round of interview questions were designed to see how the students would utilize information in determining relative radioactivity. All of the ranking tasks were printed in color to help the interviewees realize that C was always a different element from A, B, and D, which represent different amounts (C always had the same number of radioactive atoms as B). In each ranking task comparison, C had the highest activity (so the order expected should be C, D, B, A). These questions were designed to determine how students may attempt to use the concepts of half-life, mean life, and decay rate to qualitatively predict radioactivity. The first comparison did not provide any additional information; the three other comparisons provided information on the two nuclei: mean life, half-life, or their decay rate. Most students believed that the larger the number of atoms, the greater the radioactivity, regardless of other considerations. "Based on the number, right ... because they are all radioactive atoms, maybe different materials, but they're all radioactive, and just the amount, I guess, makes the difference." Perhaps the best analogy came from an explanation for ranking B and C together, "because radioactive means radioactive. Like, I am trying to think of an analogy, like, 1000 pounds of paper weighs the same amount as 1000 pounds of lead." It is clear that the interviewees are trying to apply schemes that were successful in the past, but will not work in this situation.

Summary

From our interviews, it is apparent that teachers need a clearer understanding of sources of radioactivity. We have found in simple ranking tasks that few students are able to recognize environments representing the greatest danger to health from radioactivity. In still others, the perceived danger from radiation depends on the "more is more" idea that the greater the number of radioactive atoms present, the greater the health hazard (regardless of the activity, i.e., independent of the decay rate). Our students, with little scientific background, have shown a predisposition to identify human artifice and technology as the sole sources of radioactivity and contamination.

A properly designed curriculum should account for student beliefs that radioactivity is temperature specific. An instructor should also be aware of how some students may intuitively misapply half-life or mean life to radioactivity. Some of our students believed that the longer an element "lives," the more radioactive it becomes.

Our students have shown that a working definition of radioactivity is not readily accessible to most people. It is difficult for them to analyze a situation correctly or even interpret a diagram such as the ones presented here. They also are unaware of the different risks associated with different decay products. These items must be remembered in the education students as they attempt to form a non-intuitive understanding of what is radioactive.

Note

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Learning what Students Think About Quantization

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Abstract

There has so far been very little work on student understanding of the broad underpinnings of quantum mechanics. We report here on our preliminary work examining their original knowledge state. We have interviewed many students and used their responses to questions to try to categorize their knowledge and to see how it differs from expert perception of quantum phenomena. Students entering the university exhibit quite limited knowledge of the interaction of quantum mechanics. We believe that some student ideas are robust and that many ideas are constructed in response to questioning.

Introduction

Without a doubt, quantum mechanics is one of the most important scientific theories of the twentieth century. Quantum theory has radically altered our view of the physical world, while at the same time its applications have had immeasurable impact on our everyday lives. By a mere decade from now, computers will have reached a "quantum limit," where the components will have become so closely packed that quantum effects will be unavoidable.

Despite this demonstrated importance, the fraction of students who will have had a significant exposure to quantum mechanics by the time we see them is tiny, which might explain the limited focus that the physics education research community has placed on the subject up to the present. Because of our dependence on the fruits of quantum mechanics to sustain our modern life, and the continued prominence that quantum theory gains as it ages, many have predicted that more and more students will be required to learn the basics of quantum mechanics as the 21st century progresses. We, as educators and researchers need to prepare for this trend by investigating student thinking about quantum mechanics. Recently, there have been a number of studies on just this subject [Refs. 1, 2, 3, 4].

However, these investigations have focused narrowly on particular phenomena or topics in quantum theory, leaving the bulk of this large subject untouched. Although we feel that many of these previous studies are of the highest caliber, we also feel that quantum mechanics is such a new and different subject that it is important to develop a picture of how students think about the subject as a whole. This study represents a first step in mapping out students' thoughts about the "broad landscape" of quantum mechanics.

In this paper we will discuss our investigation of student thinking about a wide variety of topics, which are subsumed under the title "quantum theory," including interference and diffraction, quantization of atomic energy levels, atomic structure, the nature of light and matter, and the interaction between light and matter. Our investigation consisted of multiple series of student interviews and written surveys, which were administered to a wide range of students and faculty. We shaped our study in two particular ways to take into account our students' lack of formal exposure to quantum theory. First, we used the concept of the photon as a common thread to probe students' understanding of a wide range of topics in quantum mechanics. In addition, we built most of our survey directly from quoted statements made by students during the initial round of interviews. This was done specifically in order to minimize the impact of our "expert" understanding of quantum mechanics on the students during the interviews and surveys.

We see the study discussed in this paper as the initial step in a larger investigation. Our purpose is to shed light on the ideas that students have about quantization and related phenomena. By looking at the broad range of topics we do here, we have eschewed exploring any particular area in much depth. Despite this self-imposed limitation, however, we see this study as of great value in providing broad view of how naive students think about quantum theory. We hope to identify trends in student responses that may indicate certain patterns of thinking. These trends can be used to guide future studies and to identify specific subareas of quantum mechanics that may be of particular interest as we attempt to understand students' thinking. While we are currently in the process of undertaking such further investigations, we also hope that this paper will stimulate others who are doing similar work.

Another possible extension of this work (and one which played a major role in shaping this project) is the development of a reliable and valid instrument for characterizing the ideas of physics classes or of particular students about quantum mechanics. We hope that out cataloging of student responses about a wide variety of issues in quantum mechanics will provide rich material for distracters on such a diagnostic. Ideally, this and subsequent investigations will lead to instructional strategies and curricula that will improve student learning of quantization and other quantum mechanics concepts.

In Sec. II, we discuss the methodology we employed, interviews and surveys, to explore student ideas about the interaction of light and matter. The results of our investigations are briefly discussed in section III. In Sec. IV, the outcomes of the interviews and surveys are discussed in more detail. Sec. V constitutes our conclusions. A version of the final protocol for our interviews is presented in Appendix 1 and the survey is found in Appendix 2.

Methodology

Prior research in student ideas about quantization has focused on student ideas about topics such as the wave model of light [Ref. 3], the photoelectric effect [Ref. 1], and visualizing quantum entities [Ref. 4]. In order to identify trends in student responses that may indicate certain patterns of thinking about these specific subjects as well as others that as yet have not been explored in the literature, we have adopted here a threefold approach. We first interviewed students and faculty from a number of different college physics courses; created a survey based on the students' statements in the interviews; and, finally, interviewed a small number of students who had taken the survey to ascertain whether they had understood the questions. The latter two steps have been iterated. To begin to explore these issues, we discuss the background of the interviews and surveys.

We did not expect that most students had even heard the word "quantization" or had any idea of its meaning (an expectation verified in several interviews and on the surveys); therefore, many of our questions ask about the "photon," a more familiar term. It turned out that many students we interviewed had not even heard of photons; we shall not discuss their responses.

Original Interviews

The informal interviews allowed for in-depth exploration of the range of student ideas about quantization and were the basis for the later preparation of the surveys (discussed in Sec. II. B.). Because we initially had little idea about students' conceptual understanding in this area, and because we did not want to prejudice them by putting our words into their mouths, we planned to let their responses determine the direction of each subsequent stage of our inquiry. In particular, almost every survey item came either from specific student responses to interview questions, or from ideas implied by those responses.

We ultimately interviewed 22 people. Interview subjects included 4 undergraduate engineering majors, 2 non-science/non-engineering majors, and 2 high school students enrolled in courses in different introductory physics sequences. We also interviewed 3 physics graduate students, 2 sociology graduate students (both with extensive coursework in astronomy), and 8 physics faculty.

Our first 17 interviews were broadly focused, and included questions about mental images of a photon or groups of photons, properties of photons, detection of photons, and whether or not photons are real. The 5 later interviews included simple demonstrations of light phenomena and related questions. The complete final interview protocol, including the initial questions and demonstration descriptions, is shown in Appendix 1. Note that the questions were used as a guide and were followed up with additional questions that depended on the response of the subject and the judgment of the interviewer. Of the four different interviewers, two were physics faculty and two were physics graduate students. The interviews lasted approximately an hour; they were audio taped and subsequently transcribed.

Surveys

To see if other students had similar ideas to those found in the interviews, we created surveys from the interview data. The surveys provide a more efficient means than interviews for collecting data from a large number of students. Further interviews were used to verify the validity of the surveys and to refine them, as we discuss in Sec. II C below.

With a few exceptions, the ideas contained in all survey items came directly from interview transcripts, either as quotes or paraphrases of student comments, or as ideas that were possibly implied by them. A few items were inspired by the results of others' research [Ref. 3]. All other items reflect statements made by at least one student somewhere at some time.

Surveys were constructed using two different types of items, multiple-choice/multiple-response and Likert-scale. The multiple-choice/multiple-response items dealt with mental images and photon properties. They allowed for students to make more than one choice for each item, and each included a 3-point confidence indicator. The first two items of Appendix 1 gives two of these items that were used in all versions of the survey.

Likert-scale items are statements; students are asked to rate their level of agreement with the statements (from strongly disagree to strongly agree) on a 5-point scale. The option "don't understand" was to be chosen if the statement was somehow unclear to the student. Likert-scale items covered a wide range of topics related to photons, light, and matter.

Various versions of our survey were given to 374 undergraduate physics students in three different categories: non-science/non-engineering majors at a large public university

(120), engineering majors at the same university (170), and students in a two-year technical college at a different large public university (84). The non-science/non-engineering majors were mainly enrolled in inquiry-based courses; the others were enrolled in traditional, lecture-based courses. None of the courses or their prerequisites dealt explicitly with quantization or photons.

Of the four different versions of the survey so far constructed, three are discussed here. Version A included 4 multiple-choice/multiple-response items and 42 Likert-scale items. Versions B and C were constructed subsequently; each included 5 multiple-choice/multiple-response items and 41 Likert-scale items. Versions B and C are identical except for 3 Likert-scale items (8, 21, 40); these items on version B refer to gamma rays, while those in version C refer to x rays. Survey version B is included as Appendix 1. Version A was given to 70 students, version B to 201 students, and version C to 103 students.

For ease of analysis, Likert-scale items were assigned to categories based on the subject of each item statement. These categories, and the items from survey version B assigned to each, are listed in Table I. Since some items reflect more than one subject; they are therefore listed in more than one category.

Table I. Categories of Likert-scale items from survey versions A, B, and C. The number shown is the item number. Item numbers with no letter attached indicate items appearing on all versions of the survey.

<u>Quantization - Energy levels:</u> 5 BC, 11 A, 16 A, 18 A, 26, 29, 30, 32, 40 A, 41 A, 46

<u>Quantization - Not energy levels:</u> 5 BC, 6 A, 14, 21 A, 24 BC, 45 A

<u>Photon vs. light:</u> 14, 16 BC, 21 A, 31 A, 31 BC, 33, 34, 35 A, 36 A, 36 BC, 37, 41 BC

<u>Photons are not real:</u> 33

<u>Size:</u> 3, 4, 7, 12, 17, 35 BC

<u>Shape:</u> 11 BC, 27 BC, 38 A

<u>Producing photons:</u> 13, 16 BC, 22, 23, 24 A, 26, 27 A, 36 A, 36 BC, 44 A

<u>Color/frequency:</u> 5 A, 6 A, 6 BC, 10 A, 10 BC, 15 A, 15 BC, 20 A, 20 BC, 23, 30, 29

<u>Wave-particle duality:</u> 1, 43

<u>Observing/detecting photons:</u> 9, 19 A, 19 BC, 25, 29, 30, 36 A, 36 BC

<u>Photons as force between objects:</u> 28 A, 28 BC, 42

<u>Slit experiments and "chopping off":</u> 38 BC, 45 BC

<u>Shadows:</u> 39 A, 39 BC

<u>Photons are protons (or another part of the atom):</u> 1, 11 BC, 18 BC, 27 BC

Post-Survey Interviews

Because we used student statements as the basis for the survey questions, and because these were definitely non-standard in content, we were concerned that the questions be intelligible to students doing the survey. To make certain that students understood items, we did 3 to 5 post-survey interviews at each iteration of the survey.

Brief Results

In this section we describe some of our data.

Interviews

Student interviews showed a broad range of ideas about what photons are and about what they do. Among the mental images of photons that students identify are a particle, a wave, a composite object, a "ball" or "bundle" of light, and each of the other answer choices displayed in survey multiple-choice question 1 (Fig. 1).

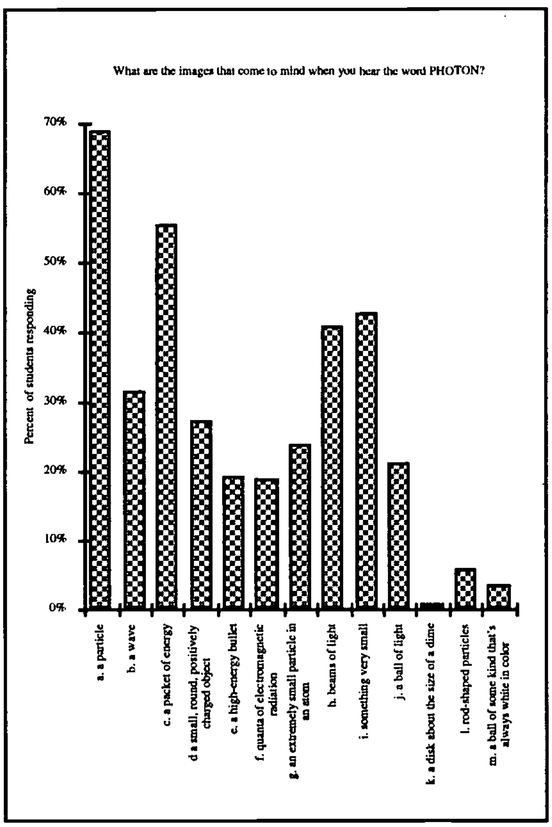

Figure 1. Responses to multiple-choice/multiple response item 1. The percent of the total number of students responding to each choice is shown.

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Some of the more colorful descriptions of mental images of photons from our interviews are:

"A little ball of light or packet of light, traveling in a continuous wave motion."

"The carrier of energy."

"Very small, extremely impossible to see."

"The atom's nucleus - several little circles or balls."

One student emphasized that "bright white sphere" was merely his mental image, and not what he thought a photon actually was: "I don't know exactly what a photon is, what it looks like, if it even looks like anything. But that's just the image I get."

Students also displayed a number of different ideas about a photon's properties. Many said that a photon's size is related to its wavelength or energy, that it is comparable to the size of an electron or an atom, that a photon can't "fit" through narrow slits that are smaller than its size, or that it has no size at all. Most agreed, however, that a photon is somehow round in shape, that its speed is very large, and that it has no mass. As one student recalled, unconfidently, "Anything moving at the speed of light can't have mass. I'm not sure if that's right either. It's just something I've heard."

The concept of photon as indivisible came up for several students in the context of a question about a light bulb that gets steadily dimmer. Most had no trouble with it, but one said,

> Maybe the least amount you could possibly have is one [photon], ... I don't know, that doesn't make much sense actually. You'd think you can always get lower and lower. But, once you get to 1, it's pretty hard to have a half of one.

The very nature of photons came into question for many students. Some said that light waves "give off photons," that photons carry light or energy, or that photons are "building blocks" or components of light. A few went so far as to say that a photon is not real, but merely a way to think about light and energy. When asked how he knew photons exist, one student reasoned, "I observe light, so if photons make up light, then photons exist."

Many other interesting comments about photons were made by students in interviews. Several of them were turned into the Likert-scale survey items that comprise survey version B (see Appendix).

Faculty and graduate students also had a wide range of ideas about photons, but they were generally more sophisticated than those of undergraduates. In their responses they frequently mentioned electromagnetic force and energy, quantum operators, gamma particles, and the wave-particle duality. Mental images of photons described by faculty and graduate students include:

"Like a squiggly arrow, like a little sine wave with an arrow at one end."

"Little high energy bullets flying out of a collision."

It is important to see how models adopted by faculty, graduate students, and some undergraduate students (those who have models) fit into the schema of the physics. Fig. 2 shows the diagram of Kidd, Ardini, and Anton [Ref. 5], which clarifies the relationship of various physically plausible models of the photon. Note that the popular corpuscular model occupies only a small section of the possible "model space." We have observed undergraduate student models that differ significantly from canonical models such as found in Fig. 2.

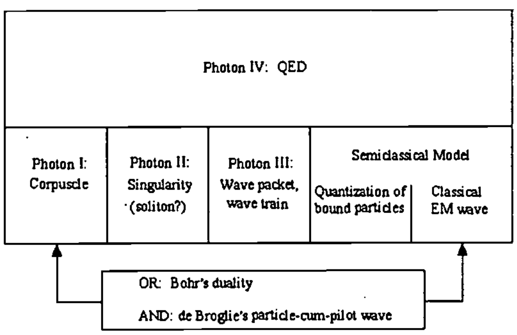

Figure 2. Kidd, Ardini, and Anton classification of photon models.

Surveys

Many of the ideas uncovered in interviews were again seen in the results of the surveys. Results were generally quite varied for each group of students, but some trends can be identified. In particular, it was found that non-science/non-engineering students answered multiple-choice/multiple-response questions more readily than they answered the Likert-scale items, even if they lacked confidence in those answers. These students frequently chose "don't understand" on Likert-scale items.

Multiple-choice/multiple-response items

Item 1, common to all survey versions, shows that for close to 70% of students, the word photon conjures the mental image of a particle (see Fig. 1). Also frequently chosen as mental images of photon were "a packet of energy" and "something very small." Other answers were chosen less frequently, although each was chosen by at least two students (out of 374).

Item 2, also common to each survey, shows that energy is one of the characteristics most commonly used for describing a photon, according to 78% of students (see Fig. 3).

Less frequently chosen, but still picked by at least 20% of students, were wavelength, frequency, and mass.

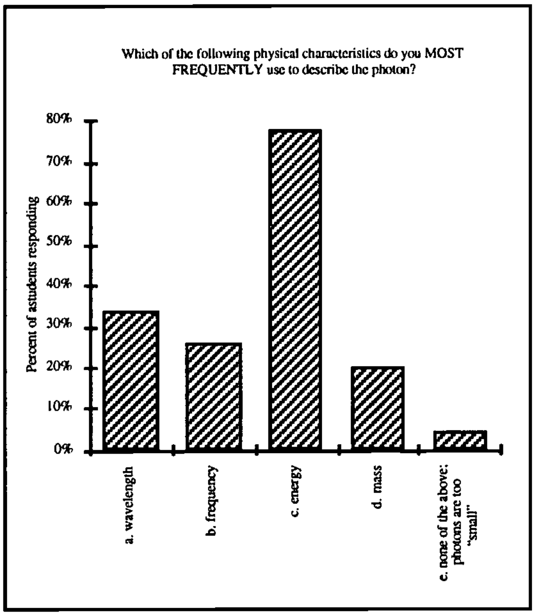

Figure 3. Responses to multiple-choice/multiple response item 2. The percent of the total number of students responding to each choice is shown.

Responses to items 3, 4, and 5 [App. 1, Ref. 6] also show little difference between groups. In these items, no answer choice is the clear winner, as each was picked by at least several students.

We could not tell much from the confidence indicator on the multiple choice/multiple response questions. There appears to be no correlation in our sample between conviction of the student and the choice of more plausible or less plausible models. Some of the most confident students, for example, chose mass as a common photon characteristic.

Likert-scale items

A complete set of data from the 66 Likert-scale items that were used in the three survey versions can be found in Ref. 6. We present here a summary and some of the highlights.

As a whole, these items show that many students have little idea of what photons are; among those who do have an idea, there is much disagreement. For each item, there were students who agreed, those who disagreed, and those who did not know whether or not to agree. Thirty-seven items out of the 65 Likert-scale items used in the various versions of the survey show a difference of greater than 20% between the percentages of students who agreed and of those who disagreed.

For many items, we expected there to be either strong support or almost no support among the students, either because these items represent facts that we thought were well-known or because they come from incorrect statements made only by single students in interviews. There was general agreement (among at least 50% of students) that photons are building blocks of light and that hot, glowing metal emits photons (items 35A/41BC, 23). However, there were surprisingly mixed responses about whether light from a bulb consists of a large number of photons, if particles exist inside photons, if photons are composed of several parts, if photons are components of atomic nuclei, if photons are simply white light, or if photons themselves produce light (items 36, 37, 27BC, 18BC, 30/29, 31BC).

We revised questions when we found through our post-survey interviews that the statements were in some way confusing. In the first version of the survey, for example, we asked students to agree or disagree with the statement (item 31A): "Photons can produce light." We expected students to disagree, because photons are light. Students, however, agreed by 60% to 17% (about 20% had no opinion). Some students interviewed told us that they agreed because photons are light, while others disagreed for exactly the same reason. We revised the questions to read (item 31BC): "Photons are not light, but can produce light." We now expected students to recognize the distinction and disagree more strongly than in survey A. A majority of students expressing an opinion still agreed after the statement's reformulation, but by a reduced margin of 40% to 20% (roughly 40% had no opinion).

Two items showed substantially different response rates (by which we mean > 20% differences among responses) among the different kinds of students. Engineering majors were almost twice as likely as non-science/non-engineering majors to agree that "You've got to excite atoms to produce photons" (item 26). Engineers were also substantially more likely than the other groups to disagree that photons are composed of several parts (item 27BC).

The non-science/non-engineering students were much less certain about the item statements; in fact, they chose the "don't know" option more frequently than the other groups on every one of the 66 Likert-scale items. This may be because they know less about photons and light—their choice of major may indicate less of an interest in science and thus they may have acquired less scientific knowledge. Alternatively, the result could be due to different levels of confidence—engineering and technical students may feel more confident in their grasp of science topics (whether or not they should be), causing them to choose "agree" or "disagree" more frequently than students outside technical fields. Items in which non-science/non-engineering students chose "don't know" with particular frequency were items relating to atomic energy levels (item 32 as well as five other items that were administered only in survey version A [11A, 18A, 40A, 41A, 45A], which are available at our website, Ref. 7) or to the color or frequency of individual photons (items 10, 15, 20).

Discussion of the Results

It appears that students have very diverse views about what photons are and what they do. This is apparent in the interviews and in the survey responses. The numbers and kinds of mental images of photons are consistent with the results of Mashhadi and Woolnough [Ref. 4]. Mashhadi and Woolnough found that different students described their visual images of a photon as a "bright ball," a "very small particle," a "packet of energy," or having "no mass or charge." These descriptions were commonly given by the students we interviewed.

It is not surprising that many of the students surveyed did not have robust ideas about photons or quantization at all. This can be seen by the frequency with which options "neutral" and "don't know" were chosen on the Likert-scale items, especially by non-science/non-engineering students. These responses were quite frequent. More striking are indications that many students who had no well-developed ideas about the photon generated ideas spontaneously when presented with either a question or options. Many students chose an answer, but indicated that they were either guessing or unsure of their responses.

This observation was supported by interview data. During the initial interviews, students would often answer a question or make a statement, but would be unable to justify it or explain why they thought it was true. This also occurred during the follow-up interviews when students were asked about their responses to particular survey questions. This might help explain the phenomenon of students selecting responses to a set of survey items that were seemingly contradictory: the students knowledge is highly unstable and their responses to questions depend greatly on the particular context or features of that question, similar to the experience of Mashhadi and Woolnough [Ref. 4] and may be based on on-the-spot mental manipulation of primitives identified by diSessa [Ref. 8]. This may have serious implications as we try to characterize student conceptions of quantization in quantum mechanics.

As has been mentioned previously, this work surveys students on a wide variety of topics related to quantization and the photon. We hope that this work will provide a helpful stepping stone towards work on how students learn about specified areas of quantum mechanics. One path towards deeper investigation is to gather student responses to questions that all relate to one topic and to categorize their responses using a system similar to that of Minstrell's *facets* [Ref. 9]. In this way, we can delve more deeply into how students think about a particular topic.

Table II. An example of facet-like items identified from student interviews and surveys. We have identified many more such ideas.

γ00	Photons are light.
γ01	Photons are defined in terms of QED creation and annihilation operators' actions on the vacuum.
γ02	Photons are building blocks of light.
γ03	Photons are the same as light.
γ04	Light is made up of photons.
γ05	Photons come in all colors.
γ06	Only if light is visible do photons exist.
γ07	Light dribbles photons off as they travel.
γ08	Photons emit light.
γ09	Photons are little particles traveling inside light waves.

One topic for which student responses have been quite rich has been the interaction of matter and light in the context of photons being emitted/absorbed by atoms as electrons move to lower/higher energy levels. We are currently using the organizational scheme based on Minstrell's facets to help us to organize and characterize student responses. An example of such organization is shown in Table II.

Conclusions

Our purpose in this study has been to shed light on general preexisting ideas that students have about quantization and related phenomena before their college instruction about quantum mechanics has begun. In particular, we looked for trends in student responses that may indicate certain patterns of thinking and set the context for further investigations of more specific ideas related to quantization.

Previous research had indicated specific student difficulties with several different aspects of what constitute quantum phenomena. We found evidence of these already-identified problems as well as other, new, ones. One finding,, specifically, is that everyone (including experts) who contemplates light quanta depends heavily on a concrete mental model. Despite existence of the idea of light as a particle, the photon, and common references to photons in the popular media, most students lack real knowledge of what this word means. Many think that a photon contains particles of light. Many fail to recognize that photons are massless. About twice as many students believe that a light wave produces photons as it travels as do not.

As mentioned previously, one of the long-term goals of this project is to develop a student questionnaire that probes student understanding of quantum physics. We feel that the results reported in this paper provide an excellent start towards this goal. We have begun to identify many topics that should be included in such an instrument. The thirty-seven items that generated the greatest disagreement between students taking the surveys are prime candidates for distractors on the final version. We hope that others will contribute results from their own investigations to this endeavor

Note

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Appendix 1: Complete Final Protocol
Student Concept of the Photon

Consider this bulb (called a showcase bulb). Imagine that I turn the bulb down like this. What will happen if I continued to turn it down, down, down. (Assume the response will be that the light will get dim) Suppose it gets still dimmer. How dim can it get? Follow up on this idea as far as possible.

Look at the showcase bulb through this slide (a diffraction grating). What do you see? How would you describe what you see?

0. Have you every heard the term "photon"? Where did you hear about it?

If **yes**, proceed. If **no**, go to light questionnaire.

1. When you hear the term "photon" used, what mental image does it bring to mind? Describe a photon to me. Tell me what it does. Did the thought experiment we did help you formulate an idea of the photon? How?

After this is done, ask them to draw a photon if they can.

2. Does the word *quantization* have any meaning for you?

3. How would you know that a photon exists?

(followup questions on this question depend on what interviewee says)

- Does a photon have mass?
- Does a photon have a size?

c. Can you (one) distinguish between photons?

d. Does a photon have speed? (How fast?)

e. Can a photon exert a force?

f. Does a photon have energy?

g. How is a photon produced?

4. Explain why you think of a photon as "real" or why not.

5. If you were to try to explain what a photon is to a 9 year old, what would you say?

6. Look at this light (excited mercury vapor). What do you see? Now take the slide (diffraction grating) and look through it. What do you see now? How is it the same or different from the showcase bulb?

Why are there several differently colored lines? How could you explain this? What would happen to this if we cut the illumination level down, down, down? What could this have to do with the photon? ... with quantization?

7. What's a shadow and how is it formed?

After a pause for the answer: How are photons (could photons be) related to shadows?

8. Please give a short description of how you think photons are related to or used in the following items:

a. fluorescent lamps
b. CAT scans
c. (IR) remote controls for TVs, VCRs, stereos, etc.
d. x-ray machines

Finish the interview by answering the student's questions or talking to the students about the photon. Use this as an opportunity to educate the student.

Appendix 2: Survey Version B

Give the best answer(s) to the multiple choice questions.

1. What are the images that come to mind when you hear the word PHOTON?

(Circle all that apply.)

a. a particle

b. a wave

c. a packet of energy

d a small, round, positively charged object

e. a high-energy bullet

f. quanta of electromagnetic radiation

g. an extremely small particle in an atom

h. beams of light

i. something very small

j. a ball of light

k. a disk about the size of a dime

l. rod-shaped particles

m. a ball of some kind that's always white in color

n other (please explain):___________________________

2. Which of the following physical characteristics do you MOST FREQUENTLY use to describe a photon? Circle all that apply; more than one answer could be correct.

a. wavelength

b. frequency

c. energy

d. mass

e. none of the above; photons are too "small"

If you circled (e), explain what you mean by "small."

My confidence: very certain confident not very confident

3. Which of the following BEST describes the size of a photon? Circle all that apply; more than one answer could be correct.

a. photons have no size

b. the size of an atom

c. the size of a nucleus

d. the size of an electron

e. smaller than an atomic nucleus

f. photons come in a variety of "sizes"

If you circled (f), explain what you mean by "sizes."

My confidence: very certain confident not very confident

Note: If you answered (a) to question 3, you may skip question 4 and go directly to question 5.

4. Which of the following has/have to do with the size of a photon? Circle all that apply; more than one answer could be correct.

a. energy

b. wavelength

c. mass

d. frequency

e. amplitude

My confidence: very certain confident not very confident

5. The word "quantization" refers to

a. the separation of the parts of light into their component frequencies.

b. the separation in energy levels in atoms.

c. the fact that photons can have certain energies, but not ANY energy.

d. the partitioning of photons into parts.

e. the explanation of energy levels in atoms.

f. how much energy something has internally.

Circle all that apply above; more than one answer could be correct.

My confidence: very certain confident not very confident

Use the scale from strongly disagree to strongly agree to respond by circling your answer on those questions asking for this rating. ***Neutral*** means that you neither agree nor disagree, ***Don't understand*** means that you have no idea at all what the question is about.

strongly disagree disagree neutral agree strongly agree don't understand

6. An individual photon can have any single frequency in the spectrum.
7. A photon is much smaller than an electron.
8. Microwave ovens give off gamma ray photons.
9. Some photons can be seen by the eye, but only if there are large numbers of them.
10. An individual photon contains all the frequencies of the spectrum.
11. Photons are spherically shaped, like protons or neutrons.
12. A photon is a point. It doesn't really have a size.
13. Wiggle a charged particle and it creates photons.
14. The photon is a part of light and quantization means the separating of these parts.
15. An individual photon can have only frequencies that are in the visible region of the spectrum.
16. A light wave produces photons as it travels.
17. A photon is a few nanometers across.
18. The photon is a part of the nucleus in an atom.
19. A single photon of the right type can be seen by the eye.
20. An individual photon doesn't have a frequency, but collections of photons do.
21. Gamma ray photons that hit the body are hazardous to a person's health.
22. Smash two nuclei together so that they join and make a new nucleus. You will produce photons because the new nucleus you make will have a different rest mass than the sum of the other two rest masses.
23. If you heat metal so that it glows, it emits photons.
24. I have no idea of what "quantization" means.
25. Decent enough photographic film can detect one photon hitting it.
26. You've got to excite atoms to produce photons.
27. Photons are composed of several spherical parts, like atoms are.
28. The force between two charged objects is caused by an exchange of photons between them.
29. A photon is white light.
30. If somebody did an experiment where they were able to knock electrons out of anything using light waves, it would show that photons behave as particles.
31. Photons are not light, but can produce light.

32. When electrons change their energy levels in an atom, photons are being absorbed or emitted.

33. The photon is not real, it is only a way of thinking about light and energy.

34. A photon is a particle that carries light.

35. A photon is about the same size as a proton.

36. When you see the light coming out of a bulb, there're millions and millions of little photon particles that come out.

37. There are particles of light inside the photon that move at the speed of light.

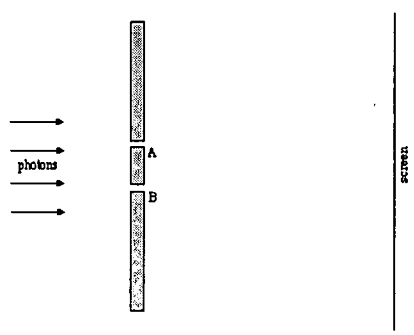
38. When a photon travels through a slit of width less than its amplitude, only part of it gets through the slit (it gets "chopped off").

39. Shadows are caused by the absence of photons, because a photon can't get through the object casting the shadow.

40. Gamma rays that hit the body are hazardous to a person's health.

41. A photon is a building block of light.

42. The reason that the electrons in atoms don't just fly off into space is because they pass photons back and forth with the nucleus.



43. Photons do funky things. If a single photon goes through a double slit (slits A and B, above), that photon actually goes through both slits A and B at the same time.

44. Microwave photons that hit the body are hazardous to a person's health.

45. When a photon travels through a slit of width less than its wavelength, only part of it gets through the slit (it gets "chopped off").

46. When the electron in a fluorescent light bulb drops from a higher to a lower state, it fluoresces as it collides with photons.

Virtual Reality on the Web: A Vehicle with New Ways to Enhance Spatial Visualization

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Introduction

In recent years, the rapid development of the Internet and multimedia capabilities has led to rapid innovations in the fields of science, education, business, and other domains. One of the most promising applications of the infobahn lies in education. A widely recognized strength of the Internet lies in its vast arsenal of data and documents (Pea & Gomez, 1992).

The potential of computer networks to revolutionize education has been widely acclaimed. Unfortunately, much like the earlier technologies of television and film, the envisioned promise of computer networks has remained largely unfulfilled (Solis, 1997).

The World Wide Web provides a colorful window into cyberspace through text, images, audio, and video. However, these formats tend to reflect purely 2-dimensional presentations of information and offer limited abilities for user involvement. Although the user can switch from one Web page to another through hypertext links, he or she remains largely a spectator. The experience is not much different from channel surfing on the television set.

All this is about to change. Since the mid-1990s, a promising new technology has appeared in the form of virtual reality (VR) on the Internet. The technology allows for the simulation of 3-dimensional worlds on a 2-dimensional computer screen. Through a simulated control panel known as a dashboard, the user can explore the virtual environment in any direction: moving forward, backward, up, down, and sideways or spinning on the spot. Moreover, the interaction occurs in real time. For instance, if the user drops a pen, it begins to fall immediately toward the ground. (The response time for the simulation will, of course, depend on the processing power of the computer system at hand.)

As explained above, first-generation Web technology provided largely a passive experience for the user. For students, the presentation was only marginally better than a book or a television set. If the first generation offered a window into cyberspace, then the second generation using virtual reality provides a doorway into an electronic universe. Although certain sensory models such as olfaction and taste remain unaddressed by the current technology, VR on the Internet provides a more intensive experience than before. This technology permits a student to participate actively and thereby bring the subject matter more closely into the realm of personal experience as opposed to dry fact.

In the literature, several studies have reported on training materials to enhance spatial visualization abilities in general and spatial visualization in particular. To date, most of the programs have focused on the manipulation of physical objects. However, the use of tangible objects is subject to drawbacks such as procurement cost, storage space, restricted access, and mechanical failure. These limitations underscore the need for materials which transcend the constraints of temporal access and physical space. To this end, VR on the Internet represents a promising vehicle to enhance the learning environment.

The next section presents the background behind spatial visualization as well as VR on the Web. The material is followed by a case study in the form of an educational program to enhance spatial visualization. The concluding section presents some final remarks and directions for the future.

Background

Spatial Visualization

Spatial visualization represents a subset of spatial skills. The former has been described by McGee (1979) as "the ability to mentally manipulate, rotate, twist, or invert a pictorially presented stimulus object." According to one school of thought, mental manipulation is the primary task in spatial visualization (Ben-Chaim et al., 1988; Macoby & Jacklin, 1974).

The importance of spatial visualization springs its relationship to most technical and artistic occupations including mathematics, science, art, and engineering. However, spatial visualization is not one of the standard components of the school curriculum. Rather, spatial reasoning is acquired informally through informal channels.

Even so, several studies of training programs to improve spatial visualization have been reported in the literature, in concert with various theoretical analyses and hypotheses regarding spatial visualization ability (Ben-Chaim et al., 1988; Battista, 1990; Battista & Clements, 1996; Lean & Clements, 1981).

To date, a number of studies have concluded that spatial visualization appears to be an innate ability not amenable to specific instruction. However, the present study presents some countervailing evidence.

Virtual Reality on the Internet

All over the globe, increasing volumes of information are being created, captured, or converted into digital form. For instance, documents are first drafted on personal computers while hand-drawn figures are encoded through digital scanners, and traditional works of art are transformed into electronic images. Further, the rapid interconnection of previously isolated computers has led to the accessibility of both public and private information through electronic networks.

To an increasing extent, computer networks permeate everyday life at school, home, and office. For this reason, the information highway is an obvious tool for delivering educational programs.

Virtual reality on the Internet is a technology that allows for the fusion of multimedia files ranging from text to video. In addition, the technology offers a novel capability through its ability to present simulated 3-dimensional worlds.

VR on the Internet has been implemented through various formats. Perhaps the most versatile among these standards lies in the Virtual Reality Modeling Language (VRML). The language provides a relatively compact description of 3-D worlds which can be rendered or depicted using appropriate software.

VRML is a complement to the HyperText Markup Language (HTML), which specifies how information should be presented in a 2-D format on a computer screen. The complementary nature of HTML and VRML is illustrated by a program in which HTML is used to specify a window on a computer monitor. For this application, HTML could be used to partition the window into several frames, one of which might present a 3-D world specified through VRML; another frame might provide explanatory material for the VRML world through text and 2-D images specified in HTML.

A third complementary standard lies in the Java programming language. Java is a general-purpose language which can be used to depict objects in HTML or control a VRML world. For instance, an applet is a small program written in Java which may be used for, say, providing an animation of a dog running across a 2-D scene whose overall structure is specified in HTML. In an analogous way, Java can be used to process information or specify complex relationships among objects in a 3-D world whose overall organization is specified in VRML.

The technologies of HTML, VRML, and Java provide a versatile vehicle for presenting information to students in multiple media formats. HTML can be used to lay out the 2-D presentation on the screen, while VRML provides a 3-D multisensory experience, and Java is used to control behaviors within and between the following interfaces: the 2-D screen, the 3-D world, and complex interactions with the user.

The present study involves the creation of software using VR to enhance spatial visualization skills, followed by an analysis of its efficacy. Differences in the performance among the students on a spatial visualization test were investigated, both before and after instruction using the software. More specifically, the study was designed to address the following questions:

1. Does Web-based instruction in spatial visualization affect the attendant capabilities among students?

2. Do the effects differ for spatial visualization instruction through virtual reality in comparison to simple text and graphics?

3. Which sub-factors of spatial visualization are affected the most by the use of virtual reality on the Web?

Method

Participants and Setting

The study was conducted in fall 1999 at two girls' high schools in neighboring districts in southern Korea. The schools were the most prestigious in their respective districts, and were of equal caliber as measured by scores on a nation-wide entrance exam. Each of the two schools featured about 50 PC's in its computer laboratory, all of them with full Internet connectivity.

All students in the sample were members of tenth-grade computer classes taught by mathematics teachers. The two teachers, both male, had recently become digital enthusiasts and wished to introduce their students to the potential of the Internet.

Ideally, each class in each school should be partitioned into treatment and control groups. However, given the public accessibility of the Website, there would be no way to restrict access to a program designed for one group from curious members in the alternate group.

For this reason, the partitioning was effected by schools. In other words, the class in one school, comprising 36 students, constituted the treatment group. Meanwhile, the 31 students in the other school comprised the control group. Spatial visualization software using VR was employed for the experimental group, while software composed only of text and 2-D graphics was used for the control group.

The network environment for the study is depicted in Figure 1. All the materials used in the study were made available on the WebMath site. The students were taught to download and use the software from this resource.

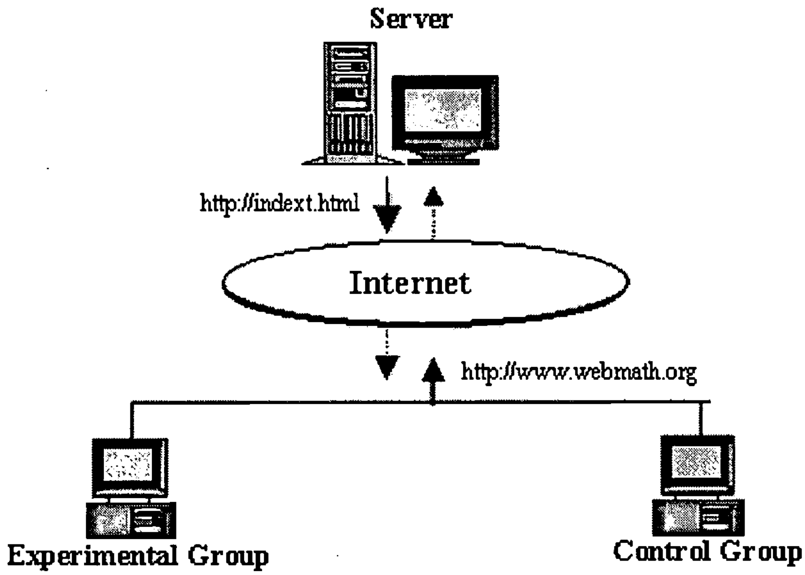

Figure 1. Network configuration for the experiment.

Procedure and Data Collection

Prior to the experiments, a one-day orientation in each school for the teacher involved was conducted. All the materials, including a detailed teacher guide, were provided to each instructor. Moreover, the author was available to the teachers for consultation throughout the study.

Before embarking on the instruction, all the students were administered the Middle Grade Mathematics Project (MGMP) Spatial Visualization Test to obtain a baseline and background information on their skills. The Test was developed by the (MGMP) funded by the National Science Foundation (Ben-Chaim et al., 1988). The permission to use MSMP Test was given by Lappan at Michigan State University. Thirty-two multiple-choice items, each with five options, comprise the test. The test is an untimed test with 10 different types of items. The types of representations used are as follows: two-dimensional flat views, three-dimensional corner views, and a "map plan," which depicts the base of a building using numbers within squares to indicate the number of cubes to be placed on each spot. The test includes tasks such as finding either flat or corner views of "buildings," adding and removing cubes, combining two solids, or applying the notion of a "map plan".

All the tests were conducted by the classroom teacher. However, the students individually studied the material at home or in the computer laboratory at school.

After the pretest was given, all the students studied the software on the Web. The material required an average of about 2 hours of study, spaced over a period of approximately 2 weeks in December, 1999. Then the posttest was administered immediately after the end of this period.

Case Study

A vital aspect of effective learning is the engagement of the student as an active participant. The use of virtual reality as a vehicle for education offers the following advantages.

Student interest. VR offers a lively medium with a richer sensory texture than 2-D platforms such as books or television. The medium naturally attracts the student's attention. A motivated student is more likely to absorb and retain the material presented. In addition to the inherent attractiveness of VR, our case study elicits interest by presenting the target material in the form of a game.

Multiple media. An amalgam of visual media helps to capture the student's attention and to develop a mental model of the material at hand. The technology of VR offers multiple visual formats such as imagery, animation, and video. Moreover, VR provides an integrated platform for sound and text as well as visual modes. These sensory models can be combined in synergistic fashion to convey concepts in a compelling way.

Learning by doing. Many courses in the curriculum involve laboratory exercises in order to provide an immersive experience for the student. However, experimental facilities can be expensive to maintain, cumbersome to handle, time-consuming to run, and sometimes hazardous for the users. All these limitations can be reduced or even eliminated through computer simulations, while at the same time providing a realistic experience. These same factors have been prompting organizations around the world to rely on computer simulations to an increasing extent, ranging from business games to military training.

Our case study involved the development of an educational software to enhance spatial visualization ability. The software itself was implemented in VRML code. A snapshot of the primary module in VRML is shown in the left pane of the screenshot in Figure 2. By using the mouse, a student could rotate the virtual building along any axis, or "move around" to see any side of the building at will.

As shown in the figure, the VRML module was displayed in one of two key frames in the window. The overall format of the window was specified through HTML.

The task for the user was to solve a series of problems in spatial visualization. Each successful solution to a problem carries the user to the next problem.

The VR capability, including the virtual building, was used for instruction amongst the treatment group. On the other hand, the software for the control group was devoid of the virtual building, as illustrated in Figure 3.

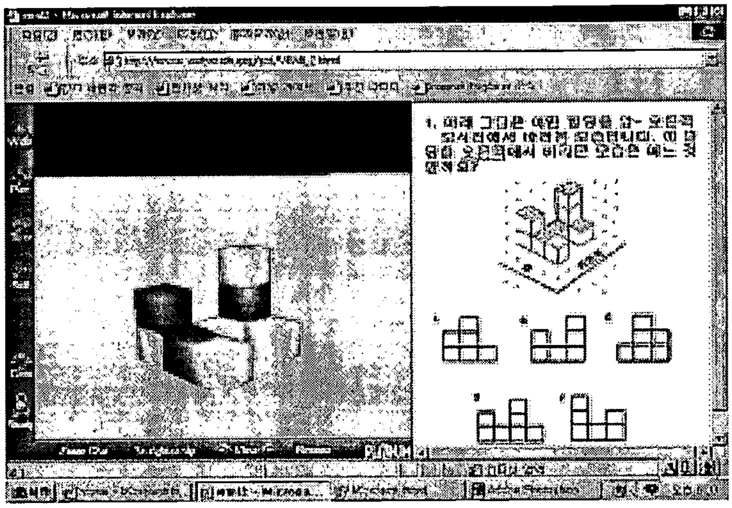

Figure 2. Spatial visualization software using virtual reality.

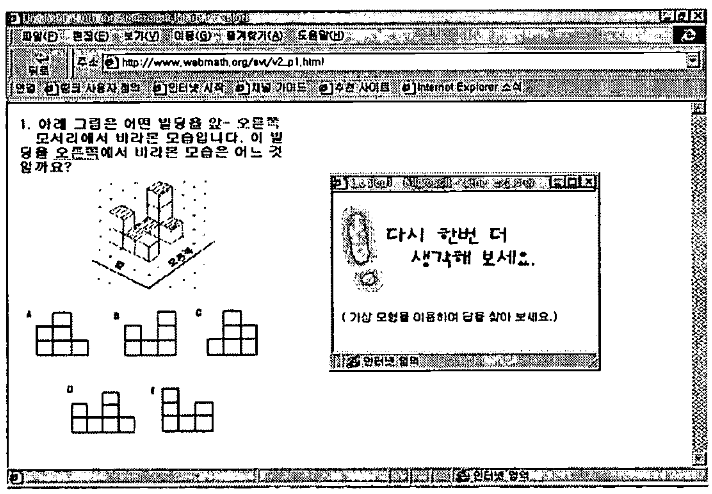

Figure 3. Spatial visualization software without virtual reality.

Data Analysis and Results

The treatment and control groups were analyzed separately; the unit of analysis for the study was an individual student. The statistical procedures used to analyze the data were univariate analyses of variance and paired comparisons on the pretest and on the gain scores.

An analysis of the pretest data was first conducted in order to determine whether the group difference in spatial visualization was statistically significant. A summary of the analysis of variance on the pretest scores for the treatment and control groups is reported in Table 1. As anticipated, the intergroup difference was not statistically significant at the .05 level. The result indicated that the two groups were relatively homogeneous in their spatial visualization skills prior to instruction.

Table 1. Comparison of the pretest scores between the treatment and control groups.

	N	Mean	Standard Deviation	t	p
Treatment Group	36	25.55	4.39	1.163	.250
Control Group	31	24.09	5.66		

An analysis of variance for the gain scores (posttest minus pretest) for the treatment and control groups separately is reported in Table 2. For each group, there was a significant overall gain on the MGMP Spatial Test. According to the t-test for two dependent samples, the t-value was -6.69 with p< .000 for the treatment group; and -3.36 with p< .002 for control group. Therefore, for each of the two groups, the difference between the pretest and posttest was statistically significant. One interesting outcome was that the standard deviation for the treatment group declined dramatically after the experiment. The result of this investigation showed that spatial visualization ability for each group improved significantly after the Web-based instruction.

Table 2. Comparison of the gain scores for the two groups.

	Treatment Group (N=36)		Control Group (N=31)	
	Pretest	Posttest	Pretest	Posttest
Mean	25.55	29.66	24.09	27.00
Standard Deviation	4.39	1.62	5.66	4.78
t	-6.69		-3.36	
p	.000**		.002*	

*p< .01
**p< .001

Table 3 presents an analysis the posttest results for the treatment and control groups. This comparison indicates the differential impact between software using virtual reality versus that without. The t-value using the t-test for two independent samples was 2.95 with p< .005. This result indicated that the instructional effect of the program using virtual reality was higher than that employing only text and images.

Table 3. Comparison of the posttest results for the treatment and control groups.

	N	Mean	Standard Deviation	t	p
Treatment Group	36	29.66	1.62	2.95	.005*
Control Group	31	27.00	4.78		

*p< .01

A detailed analysis of the pretest and posttest data by item type for the treatment and control groups is presented in Tables 4, 5 and 6. The means reported in the table are based on proportion (i.e., number of correct responses in an item type / total number of questions in the item type).

For each of the treatment and control groups, the proportions on the posttest were generally higher than those from the pretest. On the other hand, the proportions for item types 4 and 5 within the control group were lower than those from the pretest. We may infer that the spatial visualization program for the control group was not entirely consistent, since there was a differential impact on certain sub-factors of the spatial visualization skills. Even so, the two programs were generally effective since most item types showed an improvement in performance.

Table 4. Proportion of correct responses for each item type by group.

Item	Treatment Group (N=36)		P	Control Group (N=31)		p
Type	Pre-test M	Post-test M		Pre-test M	Post-test M	
1	.89	.97	.030*	.81	.71	.423
2	.91	.93	.487	.79	.79	1.00
3	.92	.96	.401	.88	.95	.017*
4	.98	1.00	.324	.95	.82	.032*
5	.70	.71	.786	.75	.66	.133
6	.87	.93	.324	.88	.93	.264
7	.83	.97	.001**	.87	.95	.071
8	.63	.91	.000***	.55	.79	.000***
9	.83	.94	.030*	.69	.88	.008**
10	.74	.93	.000***	.55	.84	.000***

*p < .05
**p < .01
***p < .001
M = Correct responses for an item type as a proportion of the total number of questions in the item type.

Table 5 presents the results of the pretest and posttest by item type for both the treatment and control groups. Item type 10 yielded a surprise: the difference between the treatment and control groups on the pretest was statistically significant at the .01 level. On the whole, however, spatial ability between the two groups did not differ significantly prior to the Web-based instruction intervention.

On the other hand, a significant difference in improvement due to the treatment was observed for item types 1, 2, 4, 8, and 10. These five item types dealt with the rotation factor, one of the sub-factors of spatial visualization. We may infer that the spatial visualization program using virtual reality was more effective than the one without. Moreover, VR software was most effective for enhancing the rotation factor in the spatial visualization task.

Table 5. The proportion of correct responses on the pretest and posttest by item type for each group.

Item Type	Pretest: Treatment Group (N=36)	Pretest: Control Group (N=31)	Pretest: p	Posttest: Treatment Group (N=36)	Posttest: Control Group (N=31)	Posttest: p
1	.89	.81	.117	.97	.86	.019*
2	.91	.79	.079	.93	.79	.032*
3	.92	.83	.489	.96	.95	.860
4	.98	.95	.330	1.00	.82	.003**
5	.70	.75	.441	.71	.66	.482
6	.87	.88	.866	.93	.93	.918
7	.83	.87	.274	.97	.95	.407
8	.63	.55	.277	.91	.79	.041*
9	.83	.69	.070	.94	.88	.212
10	.74	.55	.003**	.93	.84	.008**

*$p < .05$
**$p < .01$

Conclusion

The study investigated a number of issues relating to spatial visualization. The results were follows. First, Web-based instruction for spatial visualization was capable of improving the target skills. Second, the spatial visualization program using virtual reality was more effective than its counterpart composed solely of text and images. Finally, the Web-based program using virtual reality for spatial visualization was particularly effective for enhancing skills in three dimensional rotation.

The results indicate that certain materials which are difficult to teach in the mathematics curriculum can be taught effectively through suitable Web-based instruction. In particular, virtual reality is a versatile vehicle for enhancing spatial visualization, presumably due to its interactivity and dynamic display for the user.

The efficacy of Web-based instruction has been demonstrated through an educational program encoded in VRML. Virtual reality on the Internet provides an integrated environment for accessing the wealth of information being digitized all over the globe. Not only is access possible, but also VR offers a multisensory vehicle for presenting information in a compelling way. The active role of the user in navigating a virtual 3-D space and the instant response of the system provide an immersive experience.

One promising direction for the future lies in autonomous learning capabilities. The maturation of machine learning techniques offers a means of developing intelligent tutoring systems which can tailor a presentation not only to the basic level of expertise for a particular student, but also to his or her changing level of knowledge. The learning capabilities may be implemented using techniques such as case based reasoning, neural networks, and induction.

Such intelligence may be implemented as a kernel of a smart system for multimedia presentations. A framework for such intelligent systems has already been developed (Bordegoni et al., 1997). The framework for intelligent presentations has been adapted to software agents and their embodiment as icons (Andre, 1997). The framework may also be tailored readily to the educational environment. We plan to investigate these and related topics in the years to come.

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Regular Sessions

Developing Identity as Mathematicians through Questioning and Discourse

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All teachers want their students to be able to think. We want them to become "higher-order thinkers," "problem solvers," and "life-long learners." In the case of my own work, I want my students to form identities as learners and, more specifically, to think as mathematicians. My biggest challenge is not necessarily ensuring that my students assimilate a specific body of information and/or knowledge, but that I create an environment that is conducive to thinking and learning—to thinking mathematically.

What do you hope will happen when you ask a student to think about something, to think hard, or to think before speaking? Most of us ask our students to think every day, but few of us make our expectations explicit. Ask any group of teachers to answer the question above. Each individual will have a slightly different way of expressing what is expected to happen when a student is asked to think. As a reflective practitioner, I have to look at my own work and the work of my students to determine whether we are indeed forming a thoughtful community.

Encouraging students to examine their thought processes, to think and talk about their own thinking, can dramatically change the dynamics of a classroom. Students find out that there are many ways to solve problems, and likely there is more than one answer to any problem. "Answers" or responses are no longer just right or wrong but rather they are evidence of varying stages of thinking, solving a problem, understanding, or discovering something new. When students share their thinking, the perspectives of all learners can be expanded. Collected evidence of student thinking in problem-solving, evidence from processes and products of their work, provides the information that we as teachers need in order to make informed decisions about classroom practice.

So, what does it take to get started? We have to start by examining our own practice to ensure that we align our practice with our espoused values. From the very first day of a new school year, a critical time in the establishment of classroom norms, we communicate our values to students through our words and actions. If we believe that thinking mathematically is developed through discourse and strategic questioning, then classroom norms have to reflect those values. We have to cultivate an environment where it is safe to take risks, where students feel valued as members of a thinking community, and where students become aware of, talk about, and develop habits of mind.

Language is the foundation for thinking and for talking about thinking. Building a common language to describe cognitive processes and products promotes the establishment of classroom norms and the development of thinking skills and habits of mind. Unfortunately, children who don't experience the meaningful verbal interaction necessary to build a foundation for thinking are at a distinct disadvantage (Costa & Kallick, 2000a). Teachers must make a conscious effort to model the use of key words and phrases that refer to mental processes and products so that they become parts of the everyday discourse. Then students need ample opportunity to use essential vocabulary in order to develop fluency in talking about thinking and learning.

The goal for students to develop, express, and apply mathematical thinking--to find and solve problems--is complicated by the need for a climate that is conducive to thoughtfulness and risk taking. Students need to feel secure in sharing their thoughts and ideas, in both small and large group settings. How do we establish our norms? How do we know when the learning climate is conducive to thoughtful discourse? How do we know when the quality of student thinking has progressed? Look around in your classroom. Is there evidence of activities that are planned to engage thinking and mindful language? What do thinking and learning look like? What do they sound like? Rexford G. Brown (1993), in *Schools of Thought*, suggests several general indicators of a climate conducive to thoughtfulness.

1. The physical classroom environment. Is the environment richly textured, with much to look at and touch, including students' work? Are students encouraged to move around to gather information or to work in various groups?

2. Interaction between and among students and teachers. Is most of the talk "teacher talk"? How many students participate in discussion? Do students address one another? Does the teacher allow sufficient time for students to respond to questions? Does the teacher appear to be a learner?

3. Questioning strategies. Do the teacher or students ask open-ended questions or questions that call for analysis, synthesis, interpretation, or evaluation? Do questions drive students toward deeper understanding or comprehension of the material, or is the focus on factual recall? Does the teacher encourage students to ask questions?

4. Amount of facilitation and probing. Are students encouraged to clarify or expand their ideas? Does the teacher translate or transform concepts verbally or graphically to enable different students to grasp them? Does the teacher provide conceptual bridges to help students move from their present understandings to new understandings?

5. Discussion elements. During discussions, do students provide supporting evidence or reasons for their comments or opinions? Do teacher or students synthesize or summarize during the discussion? Is sufficient time allowed for good discussion? Do teacher or students critique the discussion?

6. Nonverbal indicators of engagement. Are students alert and engaged? If so, how many?

7. Courtesy and sensitivity. Do teacher and students listen carefully, use polite speech, and acknowledge and support one another's ideas? Do they acknowledge and accept conflicting points of view? Are there signs of humor and good will? Does the teacher praise students for their responses or help lead them from incorrect to correct perceptions.

8. Amount of reflection and self-regulation. Do teacher or students talk about thinking or reflect on the quality of individual or group thinking? Are students able to describe their thinking or problem-solving strategies? If students take notes, what do they intend to do with them?

9. Risk-taking environment. Is the focus entirely on answering correctly, or are multiple perspectives accepted? Is there general acceptance of a healthy amount of uncertainty or ambiguity? Do students explore or brainstorm? Are students encouraged to make mistakes and learn from them?

10. Uses of technology. What technologies are available to support learner-centered activities? Are students encouraged to use technology to gather, organize, manipulate, analyze, and interpret information to solve problems and make decisions? Do students use technology to create, revise, and refine products and present results of inquiry? Do teacher or students use technology to gather data and conduct ongoing assessment of learning?

All ten indicators are congruous with creating a safe environment, developing a language of thinking, and questioning to activate and engage mathematical thinking. The questions asked by Brown (1993; see also Whiteman, 1995) should lead the thoughts and decisions that drive discourse and activity in the classroom, both in the short and long term. I find it useful to gather data to better understand how both climate and mathematical thinking are developing and to support the decisions I make identifying strategies, developing mindful questions, and designing scaffolding for learning. Classroom activities should be geared toward engaging students in stimulating thought that leads to greater curiosity and enhanced levels of understanding and interest. Questioning leads the discourse that must take place for students to identify with being learners and mathematicians and to take ownership of the learning process.

Different levels of questions require different levels of thinking. Costa and Kallick (2000b) identify three levels of questioning: 1) data gathering (input), 2) processing (process), and 3) speculating, elaborating, and applying concepts (output). Input questions are designed to draw out information that is stored as prior knowledge or to activate the senses to gather data for processing at the next level. Process questions guide students to process data in many different ways such as explaining, comparing, and classifying. Output questions are designed to go beyond the process level as students speculate, elaborate, and creatively apply concepts to new situations. All levels of questioning should be used to engage students--to draw them into meaningful activities.

I am a member of a group of teachers studying reform in mathematics education. We have analyzed videotapes and transcripts of questions asked during our mathematics lessons. Our group has found that we ask mostly input questions but include several process questions during a lesson. Output questions occur with significantly less frequency. While a goal may be to increase the number of output questions in our repertoire, input and process questions are an essential part of developing mathematical concepts. All three levels of questioning must be used to develop students' ability to work with and think about data at input, process, and output levels. One cannot evaluate, generalize, and apply a principle if appropriate, meaningful data gathering and processing has not occurred! All too often, however, we back ourselves into the opposite corner. Because of our limited time periods and mandated testing programs, we fail to engage student thinking at an output level. We tend to give students data, we may give them some time to process it, and then we tell them what they should have gotten out of it because we just ran out of time. Consequently, another opportunity to engage thinking at a higher level has been denied.

Because I want my students to form identities as learners and mathematicians, I must create an environment that is conducive to thinking and learning, and specifically to thinking mathematically. I believe the first step is to cultivate an environment where it is safe to take risks--to venture out into unknown territory. Since language is the foundation for thinking and learning, I must deliberately use a language of thinking in my classroom (Tishman, Perkins, & Jay, 1995). Students need to be encouraged to think about their own thinking, to communicate their thought processes to others, and to give feedback as others communicate their thought processes. Since questioning strategies affect the level of thought processes used, it is essential to develop the ability to ask invitational questions that engage a variety of cognitive operations.

Cultivation of a thoughtful climate doesn't just happen. We have to pay attention to what we are doing. We have to question and evaluate our progress. Ongoing, thoughtful analysis of our practice, through the questions suggested as indicators of climate, provides information that is essential to continue to shape the quality of the learning environment. My students and I together create a place where we form and expand our identities as thinkers, learners, and mathematicians.

"Thinking is an engagement of the mind that changes the mind" (Martin Heiddeger, as cited in Costa & Kallick, 2000b, p. 34).

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An Introduction to Symbolic Math Guide

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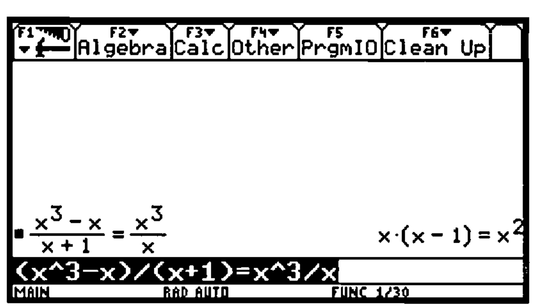
A primary purpose of the Symbolic Math Guide (SMG) is to help students develop a deeper understanding of various algorithms employed to solve algebraic manipulation-style problems. Unlike the raw symbolic manipulation utilities found on the TI-89 or TI-92, SMG is more faithful to the mathematics and mathematical notation found in textbooks. The Symbolic Math Guide was built first and foremost as a pedagogical teaching tool - not an answer generator. The program encourages teachers and students to solve problems in a step-by-step fashion in a manner similar to traditional pencil-and-paper methods.

The Need For Symbolic Math Guide

During a year-long study of CAS use with secondary school students, Edwards (2001) found that CAS students were dissatisfied with emphasis on calculator-based methods when solving manipulation-intensive problems. CAS student dissatisfaction appeared to be related to the calculator's tendency to complete large portions of problems for students.

> I think most knowledge about math is learned through hand-written work. Hand-written work gives the student a visible and mental track of what work was done and how the problem is solved. Calculators don't always show the individual steps to solving equations (Matt Fink, CAS student).

The below screenshots illustrate what happens when a student enters the equation $\frac{x^3-x}{x+1}=\frac{x^3}{x}$ on the home screen of a TI-92.

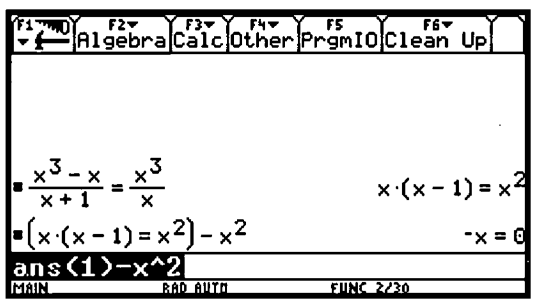


The calculator automatically performs the following tasks:

1. re-expresses $x^3 - x$ as $x \cdot (x^2 - 1)$
2. re-expresses $(x^2 - 1)$ as $(x+1) \cdot (x-1)$
3. re-expresses $\frac{(x+1)}{(x+1)}$ as 1
4. re-expresses $\frac{x^3}{x}$ as x^2

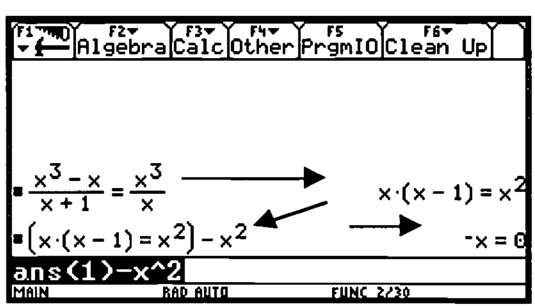
After a student decides to subtract x^2 from each side of the equation, the calculator automatically performs these steps:

1. Expands $x \cdot (x-1)$ as $x^2 - x$
2. Simplifies $(x^2 - x) - x^2$ as $-x$

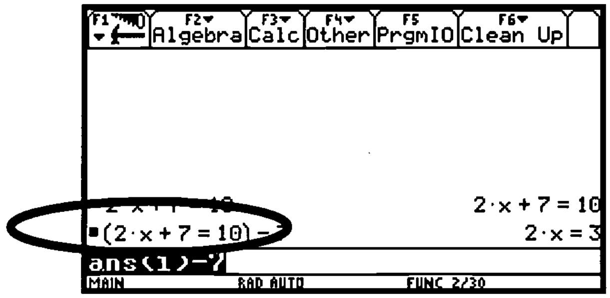


In addition, Edwards' students complained that calculator notation differed significantly from notation typically found in school textbooks:

1. Unlike conventional mathematical text, in which algebraic steps are written one below the next, TI-92 output is read from left to right, then from top to bottom (like sentences in a book).



2. Calculations in which transformations are applied to an entire equation (as opposed to each side of an equation) caused confusion with novice algebra students.

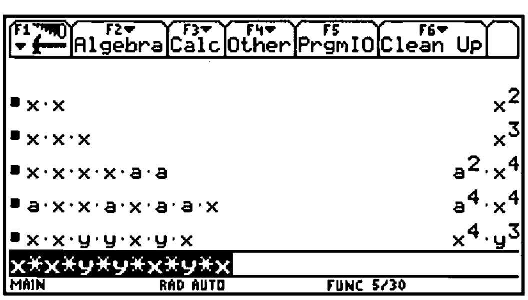


Edwards made the following conclusions at the end of the study:

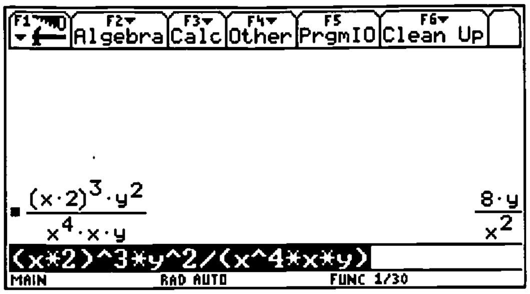
CAS based equation solving does not appear to support conceptual understanding to the same extent as traditional by-hand equation solving. The awkwardness of the TI-92 output as well as the calculator's tendency to perform "too many steps" automatically may have contributed to students' preference for by-hand methods.

Simplifying Expressions with Powers

Powers with CAS

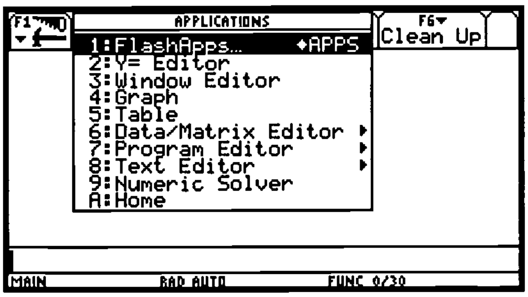


CAS allows students to discover rules about simplifying powers. By typing in several related examples into the TI-92 home screen, students form conjectures regarding algebraic rules. The examples to the left suggest a well-known "exponent multiplication" rule.

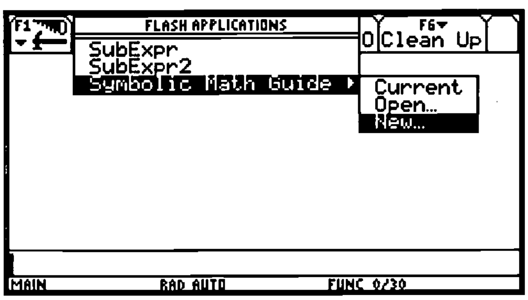


Unfortunately, the TI-92 CAS has a tendency to simplify more complicated expressions in one or two steps. This tendency creates confusion for inexperienced students, impeding their understanding of algebraic equivalence.

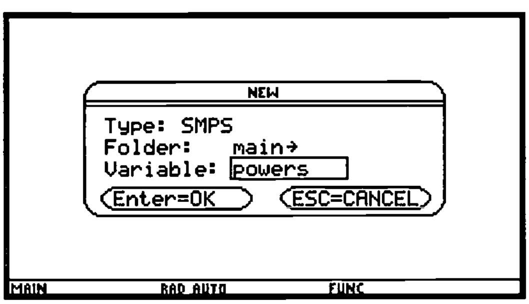
Powers with SMG - An in-depth Introduction



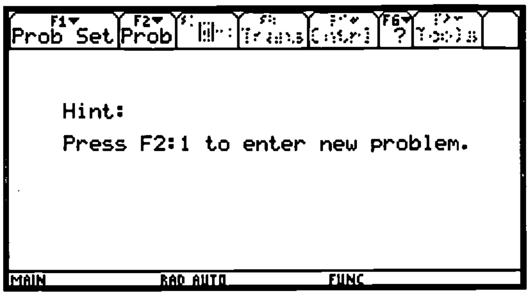
To begin using the Symbolic Math Guide, press the APPS button on your calculator. Choose the `FlashApps` option.



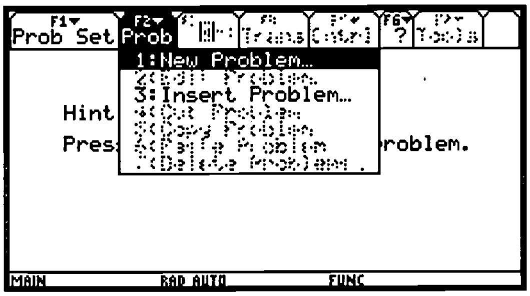
Select the `Symbolic Math Guide` `New` option. We are going to create a problem set entitled "Powers" that will contain several problems dealing with the simplification of exponents.



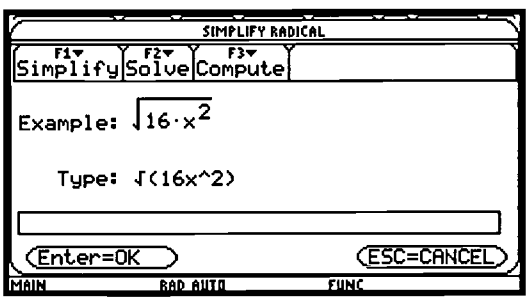
When prompted for the name of the new problem set, type in the title powers then press the `enter` button twice.



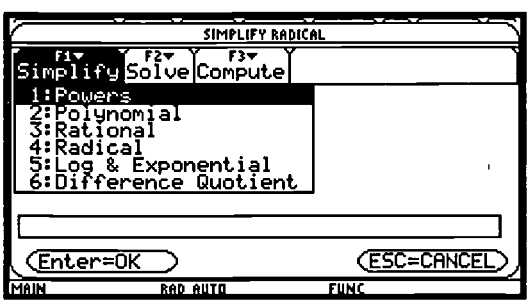
The screen to the left appears.



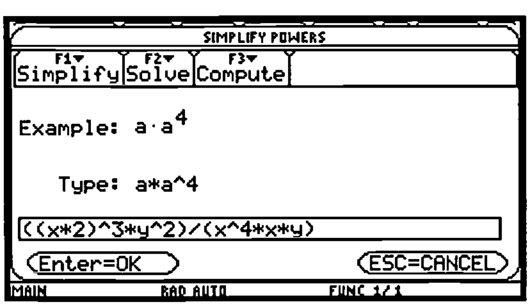
To type in a new problem, press F2 and select the `New Problem` menu option.



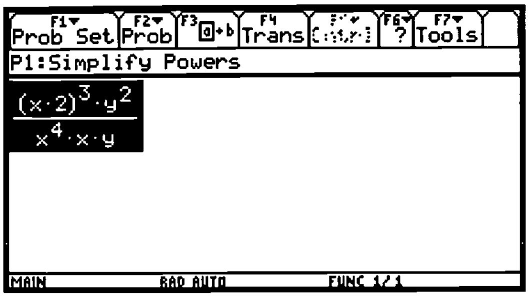
Upon selecting the `New Problem` option, SMG prompts the user to select a problem type. For instance, if a student wants to simplify an algebraic expression, he or she should press F1. Equation solving options appear under F2. Computational options appear under F3.



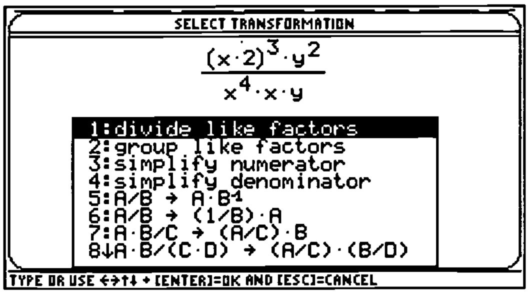
Since our first activity involves the simplification of power expressions, we select the `Powers` option underneath F1.



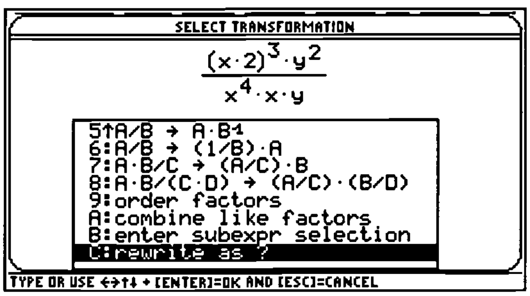
Inside the data entry line (at the bottom of the screen), type in the expression `((x*2)^3*y^2)/(x^4*x*y)` then press `enter`. The problem is now entered into the SMG main work screen.



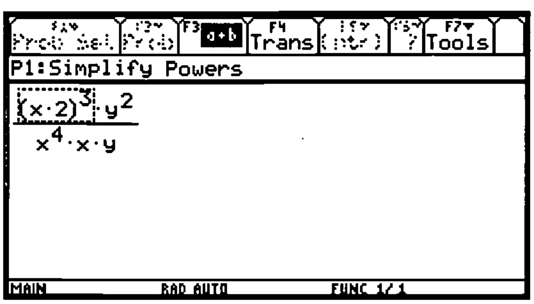
Several tools are available to the user at this point. In particular, the F3 menu option allows the user to select subexpression. The F4 menu option provides the user with different algebraic transformations that may be applied to selected expressions.



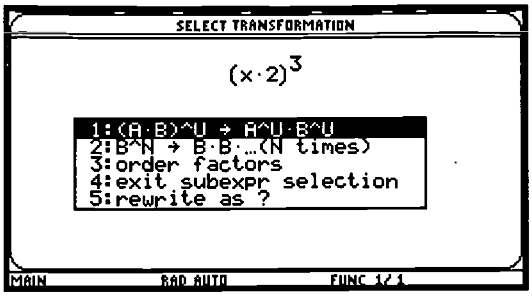
When the problem is entered into SMG, twelve legal choices are provided for the user. The student can choose any of them - although some selections lead to more efficent solutions than others. By offering legal steps, the SMG strengthens student understanding of rules used in simplifying powers.



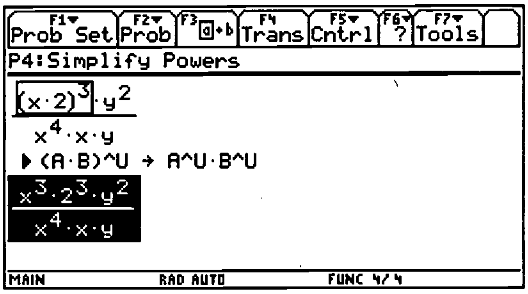
Since the twelve legal choices do not include a "power of a power" rule, students are encouraged to look at subexpressions within the problem. Students may use the subexpression feature of SMG to choose a smaller portion of the problem to simplify first.



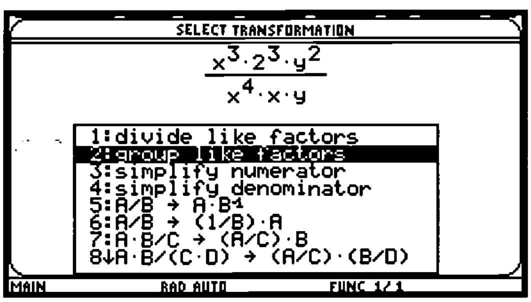
The screenshot to the left shows the selection of the subexpression $(x\cdot 2)^3$. Sub-selection is accomplished by pressing F3 and highlighting an expression with the calculator's keypad.



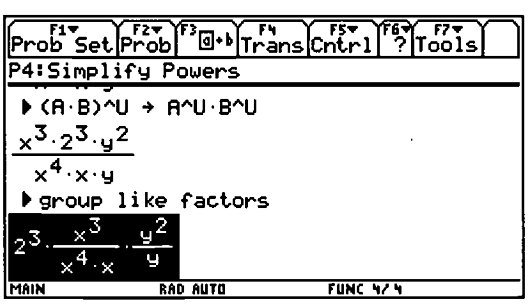
When the subexpression $(x\cdot 2)^3$ is selected and F4 is pressed, a different list of algebraic options is made available to the user.



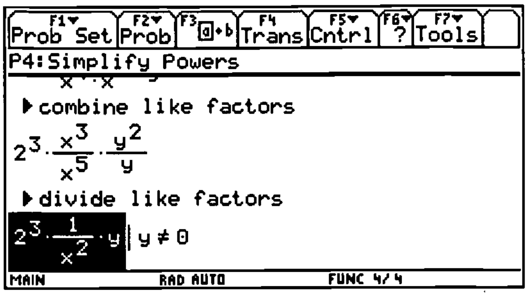
The first option - `(A•B)^U → A^U•B^U` - distributes an exponent across factors within parentheses.



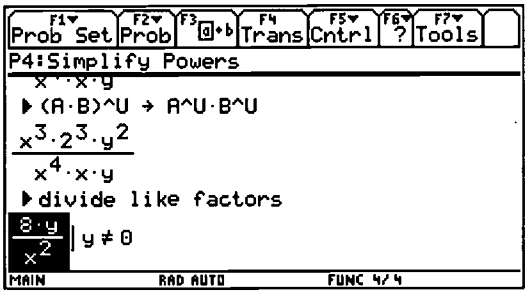
After $(x\cdot 2)^3$ is re-expressed as $x^3\cdot 2^3$, a new listing of algebraic options is once again provided to the user. The `group like factors` and `divide like factors` options are both reasonable selections.



By selecting the `group like factors` option, one is able to look at different variables combined.



The application of the `combine like factors` and `divide like factors` options makes it easier for many students to understand what is meant by "canceling out."



However, if students are already familiar with "canceling," one step cancellation is accomplished by omitting the application of `combine like factors`.

Problems for Further Investigation

1. $y^{-2}y^{4}$

2. $\frac{(x^2)^3}{x^4}$

3. $(2x^{-1}t)\ ß t^{-1}x^{2})$

4. $(-3tz^{2})^{3}\,(2t^{2}z)^{2}\,(z^{-1}t)$

5. $\frac{(2xt)^{3}\,(6x^{2})}{(x^{3}t^{2})\ \theta xt)}$

Note: If time permits, we will examine several logarithm problems with SMG and with raw TI-92 CAS engine.

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Using the "I Wonder Journal" as an Example of Open-Ended Inquiry in the Classroom

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In current educational reform the term open-ended inquiry is used frequently to describe the type of science students should be doing. However, there are many different definitions and interpretations of open-ended inquiry. One example of this interpretation is *I Wonder: The Journal for Elementary School Scientists* being used by a group of teachers in Wisconsin. The history of the I Wonder Journal, definitions of inquiry, their application to the I Wonder Journal will be described here.

History of I Wonder

" I wanted to know if I sampled kid's hands for bacteria, would age or gender make a difference in the amount of bacteria they grew?" Shaina Stewart of Lincoln Elementary not only wondered about the results of this question, but she went on to determine the answer by participating in her classroom's I Wonder Project. Shaina and others for over a period of ten years have been "wondering" about science questions and finding results. These questions are not unusual for young children or even for some adults. "From birth, children employ trial-and-error techniques to learn about the world around them. As children and as adults, when faced with an unknown situation, we try to determine what is happening and predict what will happen next" (NRC, 2000, p. 5). It is natural that students would be curious about the world around them. In order for science to be meaningful for students, educators need to be sure that these natural curiosity questions are being answered or at least researched further.

The *I Wonder: The Journal for Elementary School Scientists* began with the natural curiosity of one elementary school teacher as part of the Heron Network, Mark Wagler. Mark wanted to find a method to involve his students in real science inquiry. "The key, he thought, for linking the practice of student and professional scientists was the sense of wonder that scientists have every day as they conduct authentic inquiry. By 'wonder' he referred not only to curiosity and doubt, but also to the delightful contemplation of the mysteries of nature" (Beeth & Wagler, 1997, p. 3). He pursued this idea by working with scientists one summer to learn how they really worked. From these experiences he began to share his ideas with other teachers in his network. Based on this idea the teachers began to change the way they taught science. Teachers began by asking the students to make a list of twenty "I Wonders" and asked the students to choose a research project from that list. (Beeth & Wagler, 1997).

As the inquiries into student questions continued, the students and their teacher would meet to update the class on their progress, and their changing ideas (Beeth & Wagler, 1997, p. 5). The final result was an entire journal filled with student articles about their findings. This journal has grown and changed over ten years, but the students and teachers of the Heron Network are still pursuing their I wonder questions. *"I Wonder: The Journal for Elementary School Scientists* is unique in that it provides a mechanism for disseminating elementary students' investigations of science in a form that is analogous to printed journals within the scientific community" (Beeth & Huziak, in review). This idea is important for establishing authenticity for the students, that they are acting as scientists would.

Defining Inquiry

The challenge from the national science education standards is to create more inquiry based learning classrooms, so that students can understand and be critical of new information. Science education reform efforts in the USA stress the need for students at all levels to conduct and report scientific inquiry (AAAS, 1993; National Research Council, 1996). Inquiry is an educational term that has been used for the better part of this century starting with John Dewey's work in the early 1900's where he suggested that student should learn concepts in a natural, holistic way as they would learn them in real life. Next, Tafoya, Sunal, and Knecht (1980) devised a tool to help us classify and evaluate different types of inquiry. They state, "types of activities reflect different degrees of autonomous inquiry by students" (p. 46). According to the authors there are three major divisions: confirmation, structured inquiry, and guided inquiry. Confirmation is when the problem and solution method are given to the students and the students follow the method to arrive at a predetermined solution. Structured inquiry involves the same procedures as the confirmation; however, the students are unaware of the solution before beginning. Guided inquiry is when only the problem is given to the students and the procedures and conclusions are left for the students to determine. (Tafoya, Sunal, & Knecht, 1980).

Given these steps, then open-ended inquiry can be defined as students' determining their problem or question as well as procedures and conclusions. More recently, the National Science Education Standards (NSES) state the need for inquiry to take place in the science classroom. Inquiry is defined and interpreted in many different ways. This article will stress the definition of inquiry as stated by the NSES.

> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and considerations of alternative explanations. (NRC, 2000, p. 23)

As used by the teachers in the Heron network, I Wonder is an example of this definition in action, which can be applied to many science classrooms.

Application of Inquiry in I Wonder

As a part of the inquiry process the teachers in the Heron Network encourage students to use prior issues of the I Wonder Journal to collect information as well as to glean ideas for planning their own projects. One example of this occurrence can be seen in study of taste buds. "Barber (1996) published an article that addressed the question, 'Where are taste buds strongest?' This question was posed after reading Gould-Werth's (1995) inquiry article. What was particularly interesting in this case is that Barber actually talked with Alix Gould-Werth about revising the study she published in 1995" (Beeth & Huziak, in review). Barber was able to draw on the knowledge that Gould-Werth had already obtained and improve the study to collect additional information.

In addition to communicating with past authors, students are encouraged to communicate with students who are interested in similar questions. For example, both Zeng (1995) and Kalfayan (1995) published separate articles about building materials. Both students were testing different materials and their stability. Zeng was attempting to build cubes with his materials and Kalfayan was comparing three different materials over time. Both boys were able to communicate about their set-up and results, but they were also able to pursue their own interests.

Another often-cited need in inquiry science is data collection and variable manipulation. According to Bruce Alberts, president of the National Academy of Science, "one skill that all student should acquire though their science education is the ability to conduct an investigation where they keep everything else constant while changing a single variable" (NRC, 2000, p. Xiii). Glover (1996) conducted an experiment which tested the heart rates in boys and girls; in her study everything was constant except the variable of gender. One interesting item from her study was the use of multiple repetitions of data collection. In addition, Glover was also able to share insight for future research, if another student was interested in the same topic.

Often there are ongoing themes or questions that are of high interest to students and therefore continue to be studied. The study of crystals is one such topic. The first mention of crystals was by Tiara Lee and Keyona Moffett (1993) where both girls separately were trying to grow crystals. Two years later, Powell (1995) changed the data collection by changing the type of materials used to grow the crystals. Here planning was based on the information gathered by former students. The study of crystals continues by changing or substituting different variables in the study of crystals. In this manner students are not only gathering information, but also using it to help improve and extend knowledge.

"Inquiry in the classroom can take many forms. Investigations can be highly structured by the teacher so that students proceed toward known outcomes. Or investigations can be free-ranging explorations of unexplained phenomena" (NRC, 2000, p. 10). In the case of the Heron Network of teachers, the inquiries tend to be free-ranging; however, often a class will participate in a group inquiry. There are several examples of class projects including the "pulley project" as well as "the living machine." The living machine is a series of tanks, which contain different ecosystems in one teacher's classroom. Often cited in I Wonder are articles which pertain to the study of one aspect of this living machine. For example, Bassett (1998) observed the effects of adding a new species to the living machine.

Examples described thus far illuminate how students complete the inquiry process, but this is not what makes I Wonder inquiries unique. Many of the same strategies may be implemented in a science fair or school project completed at home. I Wonder is unique because of the written communication of ideas at the end of the project. Students are asked to write an article, which describes the question or questions they are trying to answer, the procedure used including data collection, as well as what they learned or the conclusions they reached as a result of participation in this activity. Many students also include how they would change their study if they were to try it again. As a result there is a journal published every year where students can read about other projects, as well as see their own in print. Table 1 represents the number of article that have been published every year as a part of the I Wonder project.

Table 1. Articles published in *I Wonder* (1992-2000)

Year	92	93	94	95	96	97	98	99	00	Total
# of Articles	16	63	93	93	70	56	85	87	54	617

Inquiry based teaching requires a change in the way many science teachers think about science education. The I Wonder process is just one of many avenues educators can use to help their students participate in a more authentic inquiry experience. The national education standards are suggesting that this change occur systemically across the nation. The National Research Council (1996) suggests, "Inquiry-based teaching requires careful attention to crating learning environments and experiences where students can confront new ideas, deepen their understandings, and learn to think logically and critically about the world around them" (p. 73). I Wonder fits this recommendation in a unique and meaningful way for the students.

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An Analysis of Writing in College-level Remedial Mathematics

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The National Council of Teachers of Mathematics' *Principles and Standards* (2000) states that communication in mathematics class should be an important element in the mathematics curriculum at all levels. Communication includes being able to organize, communicate, analyze and evaluate thoughts using the language of mathematics (NCTM, 2000). An essential facet of communication is writing, which is used in just about every academic subject but rarely seen in mathematics classes. Of course students write in mathematics classes, but this writing primarily consists of symbol manipulation and not the written communication of language. Mathematics as a discipline stands out in that regard, which makes it even more important to weave writing into mathematics classes. The writing process not only provides students an opportunity to clarify their own thoughts with those that are being taught, but also to augment their repertoire of representations. The writing process builds on students' previous knowledge in order to organize and create new knowledge. Writing is paramount in learning and should have its proper place in the teaching and learning of mathematics.

Currently writing is used in some classes in the form of journal writing and expository writing. Each method can serve different purposes depending on what the teacher wants to accomplish. Journal writing can be used to serve several purposes for both teachers and students. It can be a therapeutic process for students to give them an outlet in which they can vent and release their frustrations in their mathematical processes, as well as help them to improve their mathematical skills and mathematical thinking (Borasi & Rose, 1989). For teachers, using journals can be beneficial in that it provides additional opportunities for evaluation of students' knowledge and opens lines of communication between teacher and student that would not normally exist (Meel, 1999). Research shows that examining students' writing makes it possible to specifically tailor education to individuals or individual classes, which improves the overall education experience for both teachers and students (Borasi & Rose 1989; Miller & England, 1989).

Expository writing incorporates many of the same ideas that journal writing does, but is used more in an explanatory capacity as opposed to a reflection on a particular experience. This type of writing allows students to catch mistakes in addition to remembering and understanding problems better (Cai, Jakabcsin & Lane, 1996; Drake &

Amspaugh, 1994; Johanning, 2000). When students write they provide themselves with a concrete record of their thinking and mathematical processes which gives them a chance to check their work. Writing forces students to think about their thinking, which adds to their understanding by supplying them with a means to reevaluate their processes.

Powell and Lopez (1989) describe learning as a dynamic process where students move between experiences and reflections. Somewhere between the experiences and the reflections, students go through critical reflections. Writing is definitely an activity that promotes this circular idea of learning. The writing process itself is a constant automatic reflective process on experiences where writers check their thinking in order to communicate it on paper. Johanning (2000) used individual writing activities to precede group work. The collaboration with their classmates served as a check or a reflection on their individual experience, where the group work then served as an experience for yet another individual reflection. Thus perpetuating the circular method of learning that comes so naturally in writing.

This research prompted me to test some of the ideas in my own classes. The results of these tests were concurrent with the findings of the research. I used a variety of writing activities similar to those discussed in the research mentioned above. The most common aspect of the students' writing that I found was the use of exemplars. Shield and Galbraith (1998) described this feature as writing elaborated with verbal descriptions of the specific example, diagrams, conventions and graphs. The content of the students' writing samples varied from one extreme to the other and virtually nothing in between. Some samples had very little writing and explanations, whereas others justified and explained their processes thoroughly. Writing in mathematics class is difficult for some students because they are not used to writing in such a class; and they usually have not been taught how to write in a mathematics classes.

The differences in the writing styles are consistent with some findings by Shield and Galbraith (1998). They said that, "In student's writing there is sometimes a statement of the procedure in generalized language..." (p. 44). This was certainly true in my activities as some students wrote general terms and some students wrote in authoritative language. When I teach in class, I usually use the second person or just give the directions. Their textbook was written in a similar fashion. Shield and Galbraith found that students also use authoritative tones in their writing. This is probably due to the fact that they are modeling the examples given to them from the two sources of knowledge that they encounter, namely the teacher and textbook.

Another important aspect of using writing in mathematics teaching is the benefit to the teacher. Many of the researchers mentioned above identified benefits to the teacher and to the mathematical instruction. I found that using the writing samples from the students gave me an additional perspective or avenue into their understanding. Reading the students' samples was a great way to find out if they comprehend the material, if they have mastered certain skills, and if they are confused by the language and terminology. Miller (1992) identified this facet of students' writing and noted how writing can influence instructional practices.

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Integrating Social Technologies with Respect to Calculus: "Active" Learning and the Group as a Unit of Change

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This research is an exploration into issues of active learning, technology and work in groups in Calculus&*Mathematica* (Davis, Porta, & Uhl, 1999) classrooms at a large, Midwestern, state university. Teaching, writing, and learning of calculus have changed little in the past century despite enormous changes in computing technology and the uses of calculus in various fields. Classes based on the calculus of one hundred years ago focus on an appreciation of the theoretical foundations of calculus and computational proficiency. Today graphing calculators and computing technologies are used routinely to visualize, compute, and communicate, yet much of the calculus instruction tends to ignore this. These technologies reorganize classroom instruction and construct 'the student,' 'the teacher,' and 'the classroom.' Important questions arise from this discussion: 1) How is knowledge about and within calculus courses authorized and acted upon? 2) What assumptions underlie "group work" and "active learning" in this context?

Calculus&*Mathematica* is a curriculum written "from the ground up" (*Calculus&*Mathematica*:Teaching* vs. *doing*) meaning that the creators of the program attempt to create a curriculum based only on the principles and guidelines they deem important, not based on the established canon of traditional calculus. The result is the replacement of traditional paper textbooks with electronic notebooks that are executed using *Mathematica* (Wolfram, 2001) computer algebra software. Students execute prescribed commands within the electronic texts (called "courseware") causing examples to appear instantly, in contrast to paper textbooks where static examples sit on the page, immune to attempts to modify or reproduce them.

C&M courseware is the product of a "rethinking" of traditional calculus curricula and is organized around several beliefs: 1) Current technologies shape calculus curricula and pedagogies. 2) Students learn more when they engage in "active learning." 3) Cooperative learning is an effective tool for encouraging communication and "active learning." 4) People learn better when they are able to experience mathematics visually (*Calculus&*Mathematica*:Teaching* vs. *doing*). These beliefs are based on principles of "Socratic teaching," Piaget (1970), and multiple intelligences theory (Gardner, 1983). Together, the assumptions and beliefs inscribed in the courseware contribute to the production of a "C&*M* experience" in which students and teachers come together in discursive space to share and learn calculus.

C&*M* is a course designed to defy and re-examine the traditional practices of teaching calculus by making some active (and some passive) decisions about what counts as calculus and as learning, and the roles of technology, teacher, and student in the calculus classroom. Hence, the C&*M* classroom represents a fascinating site for critical interrogations into the institutions of mathematics, technology, power, and the dynamic production of knowledge and for seeking answers to the questions outlined above.

Key Concepts Used in this Study

This study employs notions of power, difference, knowledge, and technology that confront traditional meanings of these terms in an effort to demonstrate the systemic biases that they introduce (often covertly) into research analyses. Hence major concepts are herein given brief definition.

"Institution of C&M:" This study recognizes that the processes of life are dynamic and complex – that they do not reveal themselves in any one way, to any degree of completion, to everyone simultaneously. The institution of C&*M* is the complex of actions, dialogues, people, exchanges, authorizations, constructions, textbooks, assumptions, practices, and pretensions that are associated with the existence of a C&*M* course at the university. It is a swirl of ideas that resides in a discursive space – a space inhabited by people, text, and transformations simultaneously existing in multiple (non-linear) times, and in multiple physical (3-dimensional) locations. Reflections and actions of people involved with the course (as student, instructor, advisor) form the "C&*M* experience," a phrase used by the online documentation for C&*M* (*Calculus&*Mathematica*:Teaching* vs. *doing*). Simply put, the institution of C&*M* is the (anti)site of this research.

Group learning: Group learning usually refers to work produced in some form of partnership with peers. This work is usually structured or charged with specific tasks by a teacher or other authority. The terms *group learning*, *collaborative learning*, and *cooperative learning* are often used interchangeably, though this interchangeability is a site of contestation as will be shown below.

Active learning: Active learning seems to be defined mostly in contrast to "passive" learning that entails a student as receptacle model of learning. Learning by lecture is often thought of as a passive form of learning since it positions the student only as *receiver* of knowledge. In contrast, active learning positions students as *creators* or *discoverers* of knowledge. Group activity is supposed to generate and stimulate more communication between students, thereby encouraging more active forms of learning. Hence quantity of communication is closely tied to qualitative measures of active learning.

Technology: All technologies are social in nature. Technologies are viewed as practices, products, and ideas constructed (consciously or subconsciously) by humans and deployed in the realm of the social. Technologies shape and are shaped by the social. Pedagogy, computers, lecturing, group interaction, gender associations, the classroom design, the bureaucracy of which advisors and counselors are part, registration mechanisms – all are technologies at work within the C&*M* institution.

Knowledge: Systems of knowledge are produced and maintained by social construction. "Knowledge" seems to be a unit of such a system, though it is difficult to see just how such a unit could be abstracted. This study considers "systems of knowledge" to be a "vortex" of ideas, experiences, and actions continually constructed and maintained by social participation within social contexts.

Methodologies

Interrogating social relationships to knowledge demands multiple forms of inquiry. Observations provide data about the day-to-day operation of a first-quarter, C&*M* calculus class and a C&*M* differential equations class. Multiple, semi-structured interviews with three female students are used to probe the gendered shadows of the C&*M* experience and to explore the multiple roles the interviewees claim: calculus student, woman, pre-service engineer, group leader. Interviews with engineering advisors offer insight into the ways that group work is seen as one of the central tenants in the C&*M* classes. Document analysis (tests, quizzes, syllabi, information sheets) further helps to interrogate the institution of C&*M*, its political nature, and the interactions of technology and group work within that institution.

In winter quarter, 131 students from all C&*M* classes completed a survey designed to probe the ideas and hypotheses generated from analyses of interviews, and observations from the previous quarter. The survey was designed to illuminate patterns within the "general" population of the C&*M* courses. Information from interviews, observations, document analysis, and the grounded survey were analyzed using discourse analysis as articulated by Foucault (1979a, 1979b, 1991) and Mills (1997), with epistemological contributions from feminist theorists (Haraway, 1988; Harding 1993; Butler 1992), Popkewitz (1998, 1999), and Fendler (1999).

Results

Analysis of the data confirms the overwhelming complexities of C&*M* as a system of practice inscribed in a complex social context. Some ideas surface as important in describing "active learning" and groupwork in C&*M*:

Students, instructors, and advisors note both technology and group work as defining characteristics of this class. Results of a survey of all C&M students for winter quarter 2001 indicate that students feel comfortable working in groups (84.7%) and that they learn a lot from group work in their class (67.6%). Results further suggest that the C&M classes are different than other math classes (90.8%). Interviews with students suggest that group work and the heavy use of computers make this class unique among math classes they have taken before. Engineering advisors listed both computers and group work as the two things that make the class unique among the several calculus class choices at the university. The importance of these two themes is confirmed by C&M documentation, and by comments made to students by both instructors observed for this study.

Computing technologies may limit group interaction. While the cumulative response from students on the surveys portrays students as satisfied with the arrangements of the rooms and the setup of the computers for group interaction, individual interviews suggest that those views are not universal. Marlyn, a first-year student enrolled in first-quarter calculus likes group work but finds that "the biggest problem is who's going to type. Where are we going to go so that we can be situated where we can see what's going on and still manage to have a pretty discussion about how to do the problems...it limits the group. A lot of times if you're not the one actually doing the typing, you feel kind of disconnected from the group and from the work itself." Asked further whether or not computer technology was designed as a "tool of the individual," not meant to be shared, she agrees and shares an anecdote about friends of hers playing a group computer game to support her belief. Indeed the room the C&M courses are taught in is laid out in fairly traditional arrangements, with rows of tables parallel to the board at the "front" of the room – a "faces forward" arrangement that seems antithetical to group interaction.

Passive learning is still learning. While the C&*M* classroom was noisier than most calculus classrooms, students were still able to hide out. Several times in both classes, one or two students chose to hide in quiet corners, working out of the company of other humans though still communicating (actively?) with the computer. More common however was the "quiet observer" in several groups. These students seemed to be there to be pulled along on the tides of others contributions. One engineering advisor complained that whereas the course was about active learning and group interaction, some students were still able to "coast" on the efforts of the rest of their group. Such behavior would probably not be considered active learning since the students contributed little other than their presence. Yet, however passive their learning was within the group, they chose to come to class, to sit with the group, and to pay attention to what was going on around them. For whatever reasons these students chose to be silent, their silence is often the result of an active decision on their part to participate quietly. The students were probably still learning according to modes of interaction they found comfortable. Still other students choose silence as a result of exclusion from the group. Shirley, a senior chemical engineering major enrolled in differential equations describes how she felt excluded from the group since she was the only chemical engineer in a group of electrical engineers. Her withdrawal from the group was initiated by her feelings of exclusion, but she nevertheless engaged with the material and scored at the top of the class. She was, therefore, actively learning outside the group.

Computer as a group member? Both Shirley and Marlyn used the computer to engage in communication of the calculus topics at hand. This interaction between student and computer seems to satisfy the goals of generating communication and therefore stimulating active learning, suggesting that the student-computer dyad forms a virtual group engaged in some form of group work. When asked to comment on the computer as group member, both women offered personifications of the computer as an inflexible dictator of style and content. Shirley describes the computer as requiring that "you type in what you want and it's supposed to give you back – but of course then it freezes, it breaks, it doesn't want to do it and it keeps giving you those error messages." Marlyn says that she gets along "pretty well" with the computer but describes "personality clashes" such as "the fact that it always seems to be looking for the easy way out." So if the computer is imagined as a member of a group, it forms a troubled, somewhat dysfunctional group in which communication is one way, suggesting a relationship similar to that of lecturer-student, which is rarely conceived of in terms of a group learning unit.

Also problematic in these descriptions is the way in which Marlyn expresses frustration in the ways that the computer "thinks for [her]." If the computer is thinking for her, can she be thinking for herself and therefore actively learning? This suggests that the computer not a sufficient condition for active learning to occur.

Socio-economic factors of computing, active learning, and group work. Bowles and Gintis have suggested that the "rise of collaborative learning [could be viewed] as a response to a crisis not in education, but in economy" (quoted in O'Loughilin, 1999, p. 34). O'Loughlin (1999) describes some, though not all, efforts to encourage "active learning" as "part of an effort not just to reorganize the classroom but of disciplining students to adopt 'active' principles as better ways of mastering knowledge as it is dispensed by the instructor" (p. 36). He continues, defining collaborative learning according to the rule "if 'knowledge' or the 'right answer' is not up for question in the classroom, then collaborative learning is not taking place... The most important question educators can ask themselves when implementing collaborative learning is 'Do I already know the answer to my question?' If so, then asking students to collaborate is beside the point" (p. 43). Since the computer holds a formulary of prescribed answers and ways of looking at/learning the calculus, the student-computer "group" may be a group in number, but it is not truly collaborative in nature.

Conclusions

The "C&*M* institution" is a complex web of relations in which students, instructors, advisors, among many players, come together to construct a "C&*M* experience" influenced by claims to having "reformed" calculus instruction using the computer as a pedagogical technology. The courseware creators' claims to democratization of access to and construction of calculus knowledge in C&*M* courses discursively position the computer as enhancing student freedoms to co-construct knowledge, yet the computer at the same time is a tool of self-regulation, outfitted with correct knowledge as determined by the instructor/courseware creators. In mathematics, it seems as though there is very often a 'right answer.' Future inquiry and practice could offer insight into the extent to which mathematics can and should be freed from its dependence on the 'right answer.' Perhaps the problem lies with the notion that any question with a right answer is therefore the wrong question. Collaborative learning has great potential for progressive educators who wish to nurture critical thinkers with an eye toward social action. Yet collaborative learning ought to be used based not on its trendiness, nor on its perceived status as a tool to solve the educational crisis marked by "passive learning." Rather, collaborative learning should be based on the recognition that knowledge is socially constructed. Group activities become collaborative when the locus of knowledge is contested, and negotiated.

Technology offers many potentials as a tool of collaboration though its instantiation in the C&*M* classroom is currently problematic. Limited access to one screen, one mouse, one keyboard can serve as part of a design that excludes members of the group who are unable or unwilling to crowd the machine. The computer should furthermore be seen as more than a tool since it allows students to engage individually in communication of the mathematical ideas, yet it is also less than a collaborative partner so long as the computer serves as a cut-and-paste device or a repository of prescribed 'right answers.'

Note

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Curriculum and Assessment in the Age of Computer Algebra Systems

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The use of Computer Algebra System (CAS) technology in the teaching of mathematics is entering a new and crucial stage. A considerable amount of work to date has focussed on support of existing curriculum topics and existing curriculum models. Bernhard Kutzler's seminal book on teaching and learning using DERIVE (Kutzler, 1996) includes the phrase "here is an example of how CAS can be used to support an existing curriculum topic." The arguments for the use of CAS as an effective tool in supporting teaching and learning of mathematics are well established. Now comes the real work.

Curriculum models and assessment of curricula are the structures that schools and examining boards create to educate students. The two are deeply connected and the real work of CAS advocates is now to develop curriculum models in which the use of CAS is an integral part, not just of the practice of the curriculum, but, of the conception of the curriculum. A deep and thorough sifting through of topics must be done in order to decide what really has to stay for conceptual reasons and what is still extant only because of tradition.

A crucial part of this process is a demonstration of assessment using CAS. Unless we can find instruments to measure the achievement, or lack of achievement, of that learning which is possible through the use of CAS, it is destined to remain as a prop which is occasionally brought out to support and bolster the existing methods of teaching and learning.

However, in assessment we should follow the same path as we have before. We should take the current topics in current models and using those topics see how we can begin to assess students who are answering examination questions with CAS as an aid. This exercise serves the very useful purpose of bringing to light the relative triviality, in a CAS age, of some common current questions and forces us to examine their real significance as mathematical concepts. The close scrutiny of current examination questions also affords the possibility for the incorporation of more complicated questions previously beyond the scope of a time-limited written examination.

Research on Assessment with CAS Technology

A vital issue about examination questions designed to be answered with the aid of technology is "How much is a question testing mathematics and how much is it testing ability to use technology?" There is value in both, but there is a distinction. Vlasta Kokol-Voljc of the University of Maribor, Slovenia, in discussion with Bernhard Kutzler of ACDCA, Leonding, Austria chose to make this distinction by setting up a matrix with four categories which answer two questions: (i) Is the technology immediately put to use in answer to the question or does some work need to be done first, i.e. is the use of technology primary or secondary? and (ii) once the technology is being used are the operations straightforward or does the student need good ability in using the technology, i.e. is the use of the technology elementary or advanced? This gives rise to a two-by-two matrix of classification of exam questions. Kokol-Voljc then gives examples of questions which exemplify each category (Kokol-Voljc, 1999a).

Kokol-Voljc has written more extensively about the classification which has been refined and expanded in various ways (Kokol-Voljc, 1999b).

There have been a number of papers examining the impact of CAS on current national examinations with questions posed about the future of such examinations in the CAS age.

Eoghan Mac Aogáin of the University of Limerick, Republic of Ireland looked at the Irish Leaving Certificate Examinations for 1999 (Mac Aogáin, 2000) and classified questions as trivial, easy, difficult or CAS proof. Using this classification he proposes a calculation of an "index of suitability" for examinations in the CAS age that could be applied to any examination.

A review of examinations in several European countries was undertaken by Paul Drijvers of the Freudenthal Institute in Utrecht, The Netherlands who noticed several styles of approaching the issue and classified them according to the extent to which technology is allowed and, if allowed, the reward available to those who use it (Drijvers, 1998).

Roger Brown of the International Baccalaureate Organisation, Bath, UK, compared some examination questions from Australia, Denmark and the USA and noted the clear difficulties that examining boards are having in finding an appropriate approach to assessment (Brown, 1999). However he offers the view that "There will undoubtedly be an evolution in the development of setting questions that encourage the use of technology while ensuring that the primary focus of the mathematics assessment will remain on assessing mathematical concepts and understanding."

Other papers on this area of study include Fazio (2000), Lokar & Lokar (2000) & Ruthven (1997).

Bernhard Kutzler makes the case for two-tier examinations, one part with no technology allowed and a second part with any and every technology allowed (Kutzler, 2000). As Kutzler says "Two-tiered exams would be a well-balanced compromise meeting both the desires of technology supporters and the reservations of those who are concerned about the use of technology in the classroom."

Teacher Accounts of Assessment with CAS Technology

Of course the discussion of assessment must be more far reaching than simply summative examinations. Several articles are available which address this wider discussion. Many of these are in the form of teachers relating personal experiences of trying to incorporate CAS technology into their teaching and assessment.

Marlene Torres-Skoumal of Vienna International School, Austria found group assessment very effective both for improving technical competencies and mathematics achievement (Torres-Skoumal, 2000). Other benefits she observed were social integration, student awareness of assessment procedures, and improvement in the use of mathematical language.

Boz Kempski of the Anglia Polytechnic University, Cambridge, UK uses DERIVE in the teaching and assessment of mathematics (Kempski, 1988). Based on several years of experience he suggests that "students who best use the software are those who are more able and confident in Mathematics." Kempski also considered the way that students used DERIVE in examinations and was interested to observe that "more often than not, they demonstrated an inability to make the best use of the software and did not even take full advantage of the routine menu commands."

The proceedings of the 6th ACDCA Summer Academy in Portoroz, Slovenia, published under the title "Exam Questions & Basic Skills in Technology-Supported Mathematics Teaching (Proceedings Portoroz 2000)" (Kokol-Voljc et al, 2000) contains many more articles related to teaching, learning and assessment in the CAS age.

Curriculum Issues

The question of curriculum itself in a CAS age is at the early stages of discussion. Some researchers (Heid, 1988; Cabezas & Roanes-Lozano, 1998) are looking at the sequencing of certain topics in a CAS environment.

Barry McCrae & Kaye Stacey are part of a team in Melbourne, Australia that are conducting a study to "investigate the changes that regular access to CAS calculators may have on senior secondary mathematics subjects and to explore the feasibility of offering new subjects that use CAS extensively" (McCrae & Stacey, 2000). Students in three volunteer schools have been take part in the study which will result in formal assessment probably in a CAS-active environment only. The project web site is http://www.edfac.unimelb.edu.au/DSME/CAS-CAT/.

A more recent contribution to this debate is that of Helmut Heugl (2000) of Vienna, Austria who lists what he sees as seven important competencies in algebra such as the competence of recognising structures and recognising equivalence of terms and the competence of visualisation. He discusses each of the seven competencies in terms of the impact of CAS on them and goes on to suggest several different examination models which may prove more responsive to the impact of CAS than traditional examinations.

Finally, a very controversial addition to the debate is the paper arising out of the discussion between Wilfried Herget, Helmut Heugl, Bernhard Kutzler and Eberhard Lehmann about what exactly they consider to be the essential skills in arithmetic and algebra in the CAS age (Herget et al, 2000). They imagine an environment of a technology-free examination and classify problems into essentially two types: those questions which a student would be expected to answer in such a technology-free examination, i.e. without any calculator or computer, and those questions which would not be asked in such an examination. There is, in fact, a third group in the classification, which are those questions about which the authors have doubts as to where to classify them. The authors stress the point that those questions that they would not ask in a technology-free examination they find inappropriate for any examination, even one where powerful technology is allowed. As they say, "We would not ask these questions in a technology-supported exam either, because these questions appear useless as such, their best use might be to test how well a student can operate a calculator." The paper is intentionally controversial and as the authors themselves say "we deliberately wanted to be provocative and shake the mainstay of traditional mathematics teaching."

Conclusion

With many researchers and teachers around the world actively engaged in formal and informal projects on the use of CAS technology in assessment and its impact on mathematics curricula the fruits of much more labour will, undoubtedly, appear in the years to come. The essential questions, however, will remain the same: How do we assess the mathematical learning of students who have access to CAS technology? and What should a mathematics curriculum in the CAS age look like?

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Reform Mathematics within a Traditionally-Structured Course: Using Authentic Mathematical Activity to Investigate Slope-Intercept Form

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Recent reform documents such as the Principles and Standards for School Mathematics [PSSM] (National Council of Teachers of Mathematics, 2000) have called for a fundamental change in the way that K-12 mathematics is taught. These changes include not only shifts in teaching methods, but also in what mathematics is deemed important. Some of these changes involve moving from a computationally-based curriculum to one that focuses on concepts and reasoning. While a noble goal, the vision of NCTM may not be able to be reached by some teachers for various reasons. One of the obstacles standing in the way of teacher change is lack of support from the administration. Without support from the principal or department, for example, teachers may feel unable to experiment or exercise their professional judgment. Whether these feelings are accurate or not is largely inconsequential, as the feelings themselves are enough to stop teachers from moving toward a reform-based curriculum. The focus of this paper is to present, by way of an example, the argument that, even in the most traditional of structures, it is still possible to incorporate some of the useful ideas of the reform movement.

Background of the Project

This project has been implemented and changed over the last several quarters at a large, midwestern, Research I institution in the mathematics department. It has taken place in the beginning remedial algebra course that sees a tremendous variety of mathematical backgrounds. Some of the students are quite good at mathematics, but haven't taken a mathematics course in many years. Others struggle with what would be considered basic skills such as operations with numeric fractions. In an effort to address all of the different levels in the class, I often use methods that are different from what they have seen before so that the struggling students might see something that helps them finally figure out a concept, whereas the successful students might see something that deepens their understanding.

Because of my growing dissatisfaction with how the remedial course was structured – ten weeks to cover five chapters of a traditional textbook, complete with traditional assessment – I began to look outside the book for ways to address problem areas of my students. One of these problem areas was in graphing linear equations. Overall, the students were mediocre at best when it came to graphing. Some of the students could perform the assessment tasks well, but none seemed to have much of a conceptual understanding. For example, the most common response by far to the question, "What is slope?" was "y-two minus y-one over x-two minus x-one." Even when prompted further, most of them could not tell me that the slope of a line is really a measure of how steep the graph is. It was as if the computational "understanding" had completely masked any intuition of the concept, and was therefore hindering deeper understanding.

So, the goal of my project became multifold. One goal was to find a better way to get the students to understand the content of linear equations. A further goal was to do this using what I viewed as "authentic mathematical activity," meaning activity in which a mathematician might engage.

Description of the Project

To make the activity authentic, I thought about what a mathematician actually does. Contrary to the tidy proofs offered by most mathematicians, the work of a mathematician is often very messy. It involves looking at many examples, looking for patterns, making conjectures, testing and refining (or refuting) these conjectures, and finally, proof. I decided that I wanted students to get a taste of what a mathematician actually does, so I constructed this project to simulate this cycle of observe-conjecture-test.

As previously noted, the context for this activity is graphing linear equations. The treatment of this subject in the text is very traditional – plot points, graph lines, find intercepts, and calculate slopes. Because of the structure of the course imposed by the department, there was not a lot I could do to deviate from that, so I decided to use it to my benefit. I would have the students graph carefully selected sets of lines (see appendix for copies of the project handouts) by plotting points and then make observations on these lines. Typical observations would be things like, "all of the lines in set one look like they go in the same direction," or "all of the lines in set seven hit the x-axis at the same place." As students came up with observations, we would talk about the vocabulary involved, which would lead them to write more culturally-approved observations. Inevitably, the observations would cause us to need more data, so the students would solve equations for one variable or another, find intercepts, and calculate slopes. Then, instead of saying "all of the lines in set one look like they go in the same direction," they could say with certainty, "all of the lines in set one have the same slope."

These refined observations lead them to abstract the information and look at what about the equations caused such phenomena to occur. Observations would turn into conjectures, such as "when the y is by itself, the number without the x is the y-intercept." Again, vocabulary would be introduced to move towards the more standard mathematical statements. Conjectures were tested using their own data and graphing technology to provide examples and counter-examples. After refining, the students would come up with statements such as the following: when a linear equation is solved for y, the constant term of the equation is the y-intercept of the graph.

As a class, we would then investigate how to prove such a claim. Often, they thought that the examples that they had already calculated provided proof. Discussion would then take place about the sufficiency of examples to prove such broad statements. After some discussion, the students would come to realize that they needed stronger evidence than just examples. At this point, I introduced to them the idea of the general form of a line – that any linear equation can be represented as $Ax + By = C$ (with A and B not both 0) – and discussed how this could alleviate our problem of not being able to prove with examples.

To warm up for the abstract proof, we looked at specific examples and saw how to prove the statement for particular equations and lines. Then, after seeing how the argument worked, we would proceed to prove the general case. As an out-of-class assignment, they would then prove another of their conjectures, which would look something like, "two lines will have the same slopes if, when their equations are solved for y, their x-coefficients are the same." We use these two parts then to "discover" slope-intercept form of a line.

Discussion/Conclusion

As mentioned before, the students in this particular course vary widely. While many of them complain about the amount of work involved in this project, most of them enjoy it quite a bit. They work in groups to discuss real mathematical ideas. They engage in authentic activity, which many of them never imagined they could. Also, anecdotally, they show better understanding of graphing, intercepts, slopes, and the different forms of lines. Also as previously mentioned, this is a work in progress – I haven't yet figured out the absolute best way to present these topics, but I have been able to successfully work some of the reform ideas into a very highly structured traditional classroom.

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Graphing Conjectures

Part I due ___________

Part II due ___________

Part I: Graph each of the following sets of lines on a different set of axes. Set #1 is done for you below as an example. Notice that all four lines from set #1 are on the same picture.

Part II: Once you have all of the sets graphed, come up with as many observations as you can about the graphs, the equations, how the graphs relate to the equations, how the equations relate to each other, etc. For example, all of the graphs in set #1 look parallel but cross the axes in different places. Write these observations down on a separate sheet of paper, or you may find it useful to record them on the graph paper with your pictures.

Set #1	Set #2	Set #3	Set #4	Set #5
$3x + 2y = 4$	$y = 2x + 1$	$x = -3y + 2$	$y = 4x + 5$	$y = -\frac{3}{2}x + 2$
$3x + 2y = 6$	$y = 2x + 3$	$x = -3y + 7$	$y = -\frac{1}{4}x + 5$	$y = \frac{2}{3}x$
$3x + 2y = -8$	$y = 2x + (-2)$	$x = -3y - 1$	$y = 4x - 2$	$y = \frac{2}{3}x + 4$
$3x + 2y = 0$	$y = 2x - 5$	$x = -3y$	$y = -\frac{1}{4}x - 2$	$y = -\frac{3}{2}x - 1$

Set #6	Set #7	Set #8	Set #9	Set #10
$-5x + 10y = -15$	$x = 2y + 2$	$y = -\frac{3}{2}x - \frac{3}{2}$	$y = \frac{4}{5}x + 2$	$7x + 6y = -18$
$-10x - 5y = -20$	$x = -2y + 2$	$y = 2x + (\frac{-3}{2})$	$y = \frac{5}{4}x$	$-7x - 6y = -24$
$-5x + 10y = 5$	$x = \frac{-2}{3}y + 2$	$y = -5x + (\frac{-3}{2})$	$y = \frac{5}{4}x + 4$	$6x + 7y = -7$
$10x + 5y = 5$	$x = \frac{1}{4}y + 2$	$y = \frac{5}{6}x - \frac{3}{2}$	$y = \frac{4}{5}x - 1$	$6x + 7y = 14$

Example:

Set #1, Line #1

x	y
0	2
1	1/2
2	-1

Set #1, Line #2

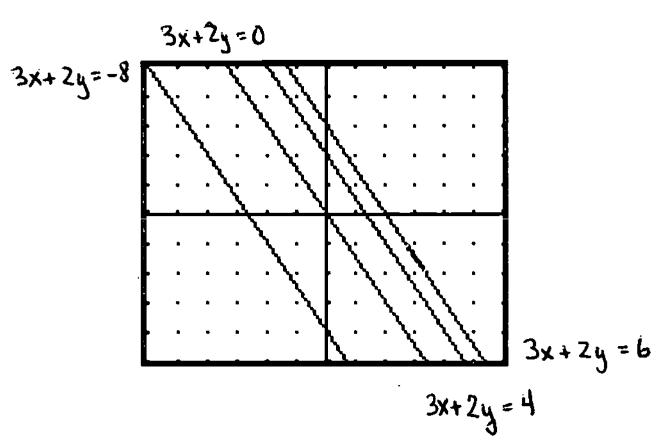
x	y
-4	9
-2	6
0	3

Set #1, Line #3

x	y
-2	-1
0	-4
2	-7

Set #1, Line #4

x	y
-3	4.5
1	-1.5
5	-7.5



Graphing Conjectures

Part III due ___________

Part IV due ___________

My assignment: odd or even (circle one)

In order to make better observations, we need some more data, so fill in the following charts for the sets of lines from the first two parts of the project.

Part III: Solve each of the equations for both x and y in either the odd-numbered or even-numbered sets, depending on your group assignment. (You will have an opportunity to share with the class to fill in for the variable you weren't assigned.) You should show your work on another sheet of paper.

Part IV: Calculate the slope, x-intercept, and y-intercept of each line you were assigned in part III, again showing your work on another sheet of paper. (Again, you will have an opportunity to get the remaining data from your classmates.)

Set #1

	Original	Solved for x	Solved for y	Slope	x-int.	y-int.
line #1	$3x + 2y = 4$					
line #2	$3x + 2y = 6$					
line #3	$3x + 2y = -8$					
line #4	$3x + 2y = 0$					

Set #2

	Original	Solved for x	Solved for y	Slope	x-int.	y-int.
line #1	$y = 2x + 1$					
line #2	$y = 2x + 3$					
line #3	$y = 2x + (-2)$					
line #4	$y = 2x - 5$					

Set #3

	Original	Solved for x	Solved for y	Slope	x-int.	y-int.
line #1	$x = -3y + 2$					
line #2	$x = -3y + 7$					
line #3	$x = -3y - 1$					
line #4	$x = -3y$					

Set #4

	Original	Solved for x	Solved for y	Slope	x-int.	y-int.
line #1	$y = 4x + 5$					
line #2	$y = -\frac{1}{4}x + 5$					
line #3	$y = 4x - 2$					
line #4	$y = -\frac{1}{4}x - 2$					

Set #5

	Original	Solved for x	Solved for y	Slope	x-int.	y-int.
line #1	$y=-\frac{3}{2}x+2$					
line #2	$y=\frac{2}{3}x$					
line #3	$y=\frac{2}{3}x+4$					
line #4	$y=-\frac{3}{2}x-1$					

Set #6

	Original	Solved for x	Solved for y	Slope	x-int	y-int.
line #1	$-5x+10y=-15$					
line #2	$-10x-5y=-20$					
line #3	$-5x+10y=5$					
line #4	$10x+5y=5$					

Set #7

	Original	Solved for x	Solved for y	Slope	x-int.	y-int.
line #1	$x=2y+2$					
line #2	$x=-2y+2$					
line #3	$x=\frac{-2}{3}y+2$					
line #4	$x=\frac{1}{4}y+2$					

Set #8

	Original	Solved for x	Solved for y	Slope	x-int.	y-int.
line #1	$y=-\frac{3}{2}x-\frac{3}{2}$					
line #2	$y=2x+(\frac{-3}{2})$					
line #3	$y=-5x+(\frac{-3}{2})$					
line #4	$y=\frac{5}{6}x-\frac{3}{2}$					

Set #9

	Original	Solved for x	Solved for y	Slope	x-int.	y-int.
line #1	$y=\frac{4}{5}x+2$					
line #2	$y=\frac{5}{4}x$					
line #3	$y=\frac{5}{4}x+4$					
line #4	$y=\frac{4}{5}x-1$					

Set #10

	Original	Solved for x	Solved for y	Slope	x-int.	y-int.
line #1	$7x+6y=-18$					
line #2	$-7x-6y=-24$					
line #3	$6x+7y=-7$					
line #4	$6x+7y=14$					

Components of Effective Professional Development

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In the present environment of educational accountability, there are widespread demands for improving student learning and academic achievement. In most states this is translated into the heightened emphasis on increasing students' standardized test scores. As a result, there is growing pressure for teachers and schools. In the state of Ohio, for example, highlights of school "report cards" listing percentages of students who pass the proficiency examination are published in local papers and announced on radio and television programs while full reports are posted on the World Wide Web (http://www.ode.state.oh.us/reportcard/). Schools that do not reach the standard for pass rates set by the state are subject to state sanction. Columbus Public Schools have been put on "academic emergency" (Columbus Dispatch, Feb. 27, 2000) and as a consequence must now submit plans for how they will ensure that their schools start meeting these standards.

Standardized mathematics tests are purported to measure conceptual understanding, knowledge and skills, and application and problem solving, which are all necessary for students to be proficient in a technologically sophisticated world. Thus, the Ohio Mathematics Proficiency exam should measure, for example, students' computation ability, problem-solving performance, and ability to communicate their reasoning, among other skills. Students, however, too often memorize steps for algorithms without understanding; therefore, they are unable to remember them or to apply the algorithms when the context of the problem is altered just slightly (Baroody & Ginsburg, 1986).

The National Council of Teachers of Mathematics (NCTM; 1989, 1991, 2000) standards documents call for a different way of teaching and learning mathematics as well as thinking about mathematics as a domain. This reform is based on a new set of goals that include an emphasis on conceptual understanding of mathematics, on learning mathematics through inquiry and problem solving, on oral and written communication of mathematical ideas, and on connections between mathematical topics and to real-world applications. These documents also set out new roles for teachers and for students. Accordingly, teachers are expected to facilitate mathematical learning by engaging students in mathematical experiences and conversations rather than simply validating mathematical knowledge. Teachers are expected to understand that students no longer passively absorb information. Rather they actively construct knowledge through problem-solving experiences that require them to provide explanations and justifications for their mathematical reasoning. Unfortunately, ten years after the publication of the first standards document there are few classrooms that truly exemplify these visions of mathematics education. (See TIMSS data, Beaton, Mullis, Martin, Gonzalez, Kelly, & Smith, 1996.)

The reasons for the lack of reform in teachers' classrooms are manifold and beyond the scope of this discussion. These include, however, a limited mathematical conceptual knowledge among teachers as a result of their limited experience with the type of mathematical interaction they are expected facilitate. In addition many teachers experience constraints on professionalism resulting from district mandated lockstep curricular materials. How might we impact this situation? In order for schools to make real gains toward reforming mathematics education and changing the landscape of low proficiency exam scores, "significant professional development will be crucial" (Ball & Cohen, 1999, p. 3). Too often teacher learning is haphazard (Wilson & Berne, 1999), characterized by short-term professional development workshops focusing on skill acquisition (Little, 1989). Long-term, systematic learning is crucial to sustained professional development. Ball and Cohen (1999) highlight the need for such efforts to go beyond the individual and often superficial workshop and to attend to the long-term "serious and sustained learning of curriculum, students, and teaching" (p. 4).

Little (1988, 1993) and Abdal-Haqq (1995) echo these calls and have put forth recommendations for professional development programs that (1) are collaborative, frequent and ongoing; (2) include training, practice, and feedback; (3) are school-based and supportive of teacher inquiry; (4) incorporate constructivist approaches; and (5) recognize teachers as professionals. In addition, professional development must provide opportunities to reflect upon one's practice while working with other professionals (Hawley & Valli, 1999). Local investigations of significant questions about instruction are an effective means to changing classroom practice (Kelly & Lesh, 1999).

Finally, within the mathematics education, content-based professional development is crucial for changing the landscape of teacher knowledge about mathematics so that they may develop instruction that is consonant with the NCTM (2000) vision. These efforts must model the instructional strategies teachers are expected to use in the classroom, thus providing a model of the reform vision of mathematics. Such long-term programs of intense, research-based, inservice professional development, reflection, and inquiry within mathematics hold promise in their potential to empower teachers, to affect long-term changes in instructional practice, and ultimately to enhance student test scores and thinking abilities.

Components of a Long-Term Professional Development Program

Based on the literature reviewed above, the first author proposed a long-term, research-based, intense professional development program that holds as a central goal significantly and positively impacting mathematics teaching and learning within the participants' classrooms. Through a series of courses over eight quarters (two years), teams of teacher-researchers are examining important issues and concepts in mathematics, mathematics education, and learning theory. The content of these courses has included: examination of NCTM Standards, Ohio Benchmarks, Local Curricular Frameworks, and their comparison; mathematical thinking and problem solving; middle-school mathematics content (e.g., proportional reasoning, variable, and function); classroom norms, culture, and discourse; culturally relevant pedagogy; technology and multiple representations; and self-regulated learning and student motivation.

The teacher-researchers' investigation of topics within mathematics education is supplemented with and complements their reflection on their classroom practice. This reflection is facilitated by weekly critique of videotapes of their classroom instruction and an examination of questioning techniques used by the individual teachers. From these reflections, teachers are asked to develop action research projects to answer local questions (i.e., questions they have about their practice). The participants will be able to share these results in various forums. Some will be developing a master's project, while others will participate and speak at national and regional conferences.

A final aspect of the program that appears to effectively engage the participants in change is the opportunity for the teachers to cooperatively plan curriculum and to discuss the ways in which they work within the curricular mandates of their districts. By sharing "tested" strategies and developing new strategies with other participants, many of the teachers are encouraged to try a new strategy within their own classroom. These have included not only new lessons, but also include change in the use of discussion, group work, and technology.

A main goal of the project is to support and document shifts in instruction toward the NCTM (2000) vision and to examine the potential of such instruction in affecting change in student outcomes. To this end, a group of Ohio State students have joined a **University Support Team,** which assists teacher-researchers' efforts to implement elements of reform that fit well with the teacher's present practice. These individuals are available in the classroom and support the teacher-researcher's efforts in various ways including direct assistance in carrying out a new lesson or method of teaching, modeling instruction for the teacher-researcher, and collecting data that the teacher-researcher will use to investigate their own research question. At a minimum of twice monthly, this group also videotapes the teacher-researchers' instruction to stimulate reflection and to document change in teaching practices.

In order to continue to encourage teacher change, the development team has been sensitive to data collected from participants while keeping in mind research on both effective and ineffective professional development. In order to impact these teacher's mathematics teaching the program has focused on issues that are important to both the researchers and the participants. By reviewing reflections, evaluations, discussions, and support team comments, we have been able to direct the teachers' attention to topics in mathematics education that allow them to become more aware of their own role in the classroom. For example, many of the teachers expressed concern of their use of questions when examining videos of their teaching. Together the university-researchers and teacher-researchers have applied research on questioning to institute change in the awareness of the role of questioning within each participant's classroom. Continued examination of research into appropriate teaching strategies and ongoing experiences with mathematics content will continue to challenge the teacher's to reexamine their own practice.

Teacher change takes a great deal of time. Over the four quarters that we have been working with these courageous teachers, we have learned a great deal about developing such a program. We have learned to be patient, to listen to the needs of the teachers, and that change comes when you might not expect it, but that when it does occur there is a reaction that can become contagious.

Note

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A High-Tech Textbook in a Precalculus Classroom

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I'm trying something new in my Precalculus classroom. When students purchased their textbooks for my class this year, they received 5 CD-ROMs rather than a bound book. These CDs and an Internet site make up the complete textbook for the course. Instead of reading 10 pages of mathematics for each section of the "book," students watch a 5 - 10 minute video lecture on the topic, and they can print off a one-page "lecture notes" document for the section (in Adobe Acrobat format) if they desire. These "lecture notes" documents, as well as the homework problems, are delivered to the students via the World Wide Web. Homework questions are all multiple choice. Students enter their answer, and before going on to the next question they are told whether or not their answer is correct. If the students miss a question, they are given an explanation as to the probable mistake they made, and they are given the correct answer with a brief justification of why it is correct.

In making the decision to use this text (which is published by a company called Thinkwell; see Burger, 2001), I felt there were three important areas where the text could have a significant positive impact on my classroom. First, instead of spending the majority of class time presenting mathematical ideas to my students, I would be able to have a master teacher present the material to students *before* they come to class (via the CDs). Thus, time in class could be spent answering student questions and exploring larger mathematical questions. I felt this text could give the class more freedom to be creative with active learning activities, group projects, and hands on applications.

The second thought I had about this textbook is that students would have more control over their learning. If students already had an understanding of a topic, they could skip through parts of the videos and go straight to the homework. On the other hand, if some students struggle with a particular mathematical concept, they have the ability to watch the presentation of the data as many times as they wish. Students also have control over *when* they are presented with *new* information. All students may not be ready to mull over new ideas at 8:00 a.m., so giving them the authority to decide when they will consider an idea for the first time is a powerful aspect of this textbook.

The final selling point for me was the homework system. Students receive *immediate* feedback on their work. This feedback is more than just telling students whether or not they got the correct answer, but the feedback is quality information. Students are able to see complete explanations of the correct responses on *every* question. This is the next best thing to having a live personal tutor with you while you complete your homework.

At Midterm, I decided to assess how the class was responding to this radically different text. Reading various articles and discussing the course with colleagues led me to regard the following the issues as pertinent to my classroom: the need for a physical classroom, control over learning, opportunity for learning, computer confidence and enthusiasm, and connections to people rather than machines. I developed a short questionnaire (see Appendix) around these issues to get input from my students (7 female and 8 male). Below, I discuss the student responses.

The Physical Classroom

Dale Spender (1995) claims that a day is coming when the physical classroom will be replaced by a virtual one. As part of her argument, Spender points out that current CD-ROM technology makes it possible for students to engage and use information in their own time. This is exactly what the Thinkwell text makes possible. Much of my students' Precalculus learning takes place outside of the classroom, and the issue of the need to meet physically in class has come up a number of times during class discussion. Thus, it was no surprise to me that it reappeared on the questionnaires. One student states, "I do think the class time is somewhat redundant, considering we spend an hour watching lecture on the CD." Another says, "… class can get a little boring, since we already learn the stuff on the computer."

These statements challenge the way traditional classroom learning takes place. In order to take advantage of the coming learning technology, and at the same time remain relevant, teachers will have to offer something different in the classroom that students cannot easily get elsewhere. What this "something different" is, I don't know. It could possibly be simply giving students opportunities to practice their math skills in class with peer tutors and an instructor close by. But this doesn't seem to be enough. I believe we should include something more dynamic such as offering students a personalized community of inquiry. This, of course, can be offered in electronic format, but I think physical interaction with other students trying to solve a common problem is more appealing than solving a problem with a group of students via e-mail (or even web-video).

Control and Opportunity

As part of her indictment against the "boring place called school," Spender (1995) describes technologies that make it possible for students to be in charge of their own learning. With the teacher stepping aside, students will have more opportunity to explore things that interest and excite them in an online, interactive, multimedia environment. In the process, learning will be increased and not compromised. This is what I expected the Thinkwell text to do for my students.

With Thinkwell, students have freedom to manipulate the videos (to replay *or* skip over them) as they complete homework assignments, and with the homework giving immediate relevant feedback to students, the assignments couldn't get more interactive - what an opportunity ... and what control! Well, you can imagine my surprise when the class was split (7 to 7) in their opinion on whether the technology enabled them to be *more in control* or *less in control* of their learning. I was again surprised to find the class was split (9 to 5) in their opinion on whether the technology provided them with a *worse* or *better* opportunity to master Precalculus.

Students complained of spending long periods of time in front of the computer (resulting in headaches for some students), not being able to ask the professor on the video a simple question, slow computers, not having many textbook examples, spending more time troubleshooting technology issues than learning the material, and having to be connected to the Internet to do the homework (this makes it tough to study on trips in the car, etc.). One student said, "Although I have learned quite a bit during this course thus far, I do believe that I would be able to learn much more [if] this technology factor was not involved." Another stated,

> Technology makes things go faster and is much easier, but there are more drawbacks from technology than positive things. In this course, I feel technology is a drawback. I am not learning... there is no benefit in using technology in this course. Plus, it is more of a hassle [than] just getting out the textbook and doing the homework.

Some of these troubles stem from problems with the technology itself, while others stem from just having access to the technology (laptop vs. desktop computer, slow Internet connections, being stuck for a weekend in a place without a computer, etc.). One thing is clear - while technology *does* present students with interesting opportunities for learning, this group of students felt the positives did not outweigh the negatives.

Confidence and Enthusiasm

It is often avowed in educational circles that students are becoming more and more comfortable with technology (Spender, 1995), but some claim women are more hesitant to approach and master technology than men (Turkle, 1999; Rasmussen and Hapnes, 1999). I desired to investigate just how comfortable students in my classroom were with technology, and to see if there were any differences along the lines of gender.

One question on the survey asked students if they were enthusiastic or hesitant at the beginning of the semester with regards to the technology. By a score of 12 to 3, students were enthusiastic at the beginning of the semester with females scoring 5 to 2. I then asked students about their enthusiasm at midterm, and I received almost opposite results. Students voted 10 to 4 (one student abstained) that they are more hesitant than enthusiastic with females scoring 6 to 1 for hesitancy. It seems the frustration with the technology throughout the first half of the semester has caused students to approach the technology more hesitantly, but this feeling looks like it is not gender-related in my classroom. Males as well as females were enthusiastic at the start and hesitant at midterm.

The survey addressed other issues related to confidence and enthusiasm. First, I asked if students considered themselves "into" technology before they enrolled in the course. Of the 15 students taking the survey, only one student (a female) said she was not into technology. Another question asked if students first play around to try to fix a technological problem or if they first ask someone for help. Without exception, *every* student said they play around first to try to solve the problem. Thus, it seems that in a situation where students are using technology to view videos and answer questions on the Web, regardless of gender, they have no problem playing around with the technology to solve technical difficulties before calling for support.

Connections

An interesting aspect of the relationship between gender and technology is what Turkle (1999) dubs the "fear of the intimate machine." In her research, Turkle observes that female computer science students rebel against having a relationship with machines. Women prefer developing relationships with people rather than controlling some sort of relationship with a computer. When they see male peers developing these techno-relationships with terminals, the women see this behavior as shutting people out. As one woman put it, "relationships are for people."

I was interested to see if anything interesting was happening in my classroom along these lines of technology and relationships. So, I asked students whether they felt more connected or less connected (1) in their relationships with other students and (2) in their relationship with the professor. For these questions, I gave students a third option to say that the level of connectedness is about the same as in classes that don't heavily use technology. It should be noted that on both of these questions, no student said they felt *more* connected with other students or the professor. The class was evenly split (7 to 8) in reporting that they felt either the same or less connected with other students, but they reported 11 to 4 that they felt less connected with the professor. I looked to see if there was any gender difference in their responses, but the opinions were evenly split with 2 female and 2 male students responding "same" and the rest of the class responding "less connected."

I feel this is an important result of the survey. Many students feel that having access to and being connected with the professor in the classroom is an important part of the learning process. It is so important to one of my male students that all he said on the written portion of the survey was, "Everything is 3." The third question on the survey was the question of connectedness with the professor. Teachers must fight through the technology to stay connected with their students.

Conclusion

I want to focus on three conclusions I've drawn from the above observations. First, as we increase the use of technologies in our classes, teachers will have to change the structure of their class time to keep it relevant and stimulating. Teachers must work to offer students a rich learning experience in class that they will have difficulty finding elsewhere. For the mathematics classroom, this learning experience could possibly be built around the idea of a community of inquiry. Second, teachers must work to help students see the opportunities for learning that technology opens up for them. Good learning technologies open up opportunities for students and gives them a tremendous amount of control over their learning (so long as they can work through the small, sometimes nagging, problems the technology brings with it). Finally, and perhaps most importantly, teachers must make a deliberate effort to develop a connection with students. This is really nothing new, but the atmosphere of the classroom will change as technology becomes more prevalent. Since technology always changes what it comes in contact with, making connections with students will look different in a technology-rich environment, and we must be equipped with strategies designed to build relationships in such an environment.

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Appendix

Questions	Please Circle Your Responses Below
1. Gender	Male OR Female
2. Does the use of technology in this course (compared to a more traditional approach) cause you to feel more or less connected **with other students**?	More Connected OR Less Connected OR About the Same
3. Does the use of technology in this course (compared to a more traditional approach) cause you to feel more or less connected **with the professor**?	More Connected OR Less Connected OR About the Same
4. When we first started the semester, were you hesitant or enthusiastic about using technology in this course?	Hesitant OR Enthusiastic
5. Now that we are almost _ way through the semester, are you hesitant or enthusiastic about using technology in this course?	Hesitant OR Enthusiastic
6. Do you feel the technology in this course gives you a better opportunity to master Precalculus, or do you feel you have a worse opportunity to master the subject?	Better Opportunity OR Worse Opportunity
7. Before enrolling in this course, would you say that you were "into" computers and technology?	Yes OR No
8. When something goes wrong with the technology, do you **first** try to play around with it to get it to work, or do you immediately have someone else work on helping you fix the problem?	Play Around First OR Get Help First
9. Do you feel the technology in this course helps helps you be more in control of your learning or less in control of your learning than in more traditional approaches?	More in Control OR Less in Control
10. Are your grades on exams Higher, Lower, or About the Same compared to other math courses you've had?	Higher OR Lower OR About the Same
11. Have you learned more math in a shorter period of time in this course?	Yes OR No

12. Please elaborate (on the back of this page) on how you think technology has helped you and how technology has hurt you in this course.

Parent Involvement

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On the "Every Parent a Volunteer" website, the following is listed as barriers to parents getting involved with their schools:

- Parents do not have enough time especially when both parents are working or when the children are from single parent homes.
- Parents feel they have nothing to contribute at the school.
- Parents do not feel valued or needed.
- Lack of childcare for young children still at home.
- Lack of transportation.
- Many parents who have less ease with the English language stay away from school.
- Parents do not feel welcome at the school.
- Parents are not available during the time school functions are scheduled.
- Parents do not understand how to get involved.
- Parents do not feel ownership in their school.

Joyce Epstein (1995) identifies six types of parent involvement as Parenting, Communicating, Volunteering, Learning at Home, Decision Making, Collaborating with Community. We are familiar with "communicating" through parent/teacher conferences and "volunteering" through room parents and other parents helping with classroom activities. Active PTA/PTO organizations may involve parents in "decision-making" processes of the school. The school can address the "parenting" issues by conducting courses or workshops that will help the parents support their children as students. The teachers can also make visitations to the home to see the child in his/her home environment.

Communication through direct contact is one of the most important forms of parent involvement. Parents are more willing to participate if they are personally contacted by a teacher who makes them feel that they are wanted by the teacher and/or school. The parents care about their children and want them to succeed. If they know that that is also your goal for their child they will be more open to becoming involved with their children's school. Early in the year the teacher should contact the parents to tell them something positive about their child. Some parents never hear anything positive from the school about their child.

They get to the point that, even though you may begin with something positive, they know that sooner or later the bomb will drop and you will tell them of a problem you are having with their child. If you make that first call completely positive, you may head off negative attitudes they and their child may otherwise have about your class. The child begins to feel good about himself/herself and the parents have something positive to relate to their child. Another advantage to two-way communication with parents is that parents can help the teacher gain insight into their child's abilities and what will help him/her learn.

Guest speakers give students an opportunity to learn where the concepts they are learning in school are used in the "real world." Parents are a good source of guest speakers. Send out surveys to learn the talents that parents have and times that they could be available to volunteer in your classroom. Employers may be happy to give the parent some time to address you class about the work the their company does. The parents can address your class about ways that their jobs, hobbies, or talents use mathematics, science, and technology. When parents address their child's class, the parents are given an opportunity to relate to their child and their child's classmates. Parents feel that their input is valued and needed. The teacher should send the parents a note to thank them for the contribution they made to the class. The teacher should let them know that their contribution was important and that their continued participation would be appreciated.

Parents do not know how or if they can help their child with his/her school work. Let them know what is acceptable. Parents should be given suggestions on how they can help their child learn. A classroom website can keep parents informed about what is going on in the classroom and what you expect of their child and them. Homework assignments can be posted on the site to let parents know whether their child has assignments, but also you can let them know what they can do to help their child with the assignment. Give assignments that will involve the parents with their children and their children's learning.

Many parents are suspicious of teaching methods that are not the same as the way they learned. With education, the parents may become supportive of the methods that you are using and become your best advocate. If you are doing innovative teaching, let the parents know about it. Have a workshop that shows the parents what you are doing and how the method you are using will help their children learn. Let students help you show their parents what you and they are doing in class. The parents can learn with and from their children.

In group interviews that I have held with parents about their attitudes on the use of calculators in mathematics instruction, I have learned that parents are concerned that their children will become dependent on the calculator. They want their child to learn to do mathematics using paper and pencil before they do it on a calculator. They want their children to learn math the way they did. Generally, they have no idea how the calculator can be used as a teaching/learning tool. Often when I give them examples of how their child can use the calculator to learn mathematics that was very tedious for them to learn, they are more receptive to letting their child use the calculator to do their math.

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Stories in Juxtaposition:
Narrative inquiry research in an urban school setting

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Narrative inquiry as a method is not widely accepted in the science education research community. This may be due to the 'non-rational' and personal nature of stories, which form the core of this method. Yet, narrative inquiry research can often reveal more about the challenges of teaching and learning than can traditional methods that rely on pre-designed protocols. Based on evolving personal stories, this method can be quite useful in revealing individuals' approaches to teaching in different circumstances.

This paper describes narrative inquiry research, provides examples, and elucidates strengths and limitations of this method.

Narrative inquiry as method

As the name suggests, narrative inquiry as a method rests on the idea of intersecting stories. Simply put, everyone has one, and when two or more people begin talking about a single topic, each brings his or her own perspective to the event. Included in one's 'perspective' are one's past experiences, knowledge, skills, understandings, and underlying assumptions about the topic, event, or activity under consideration. If the event or topic is complex, chances are that one's perspective would also be complex, though this may not always be true.

Thus, when the interaction begins, the actors may seem to stake their claims and disagree, or more likely will agree on the surface, but continue to negotiate meanings, ways of working together, and relationships as time goes on. This is a natural progression in personal experience that occurs all the time. Narrative inquiry offers the opportunity to explore the multiple perspectives of the individuals involved in a single event, or in multiple events over a period of time. It is "keeping track of the stories" of each of the players.

In support of this goal, the researcher is likely to collect and analyze various kinds of data. These may include records of conversations (via fieldnotes, audio tape, video tape), of more structured (interviews, member checks) or less formal (short chats, etc.), correspondence, reflective journals, and documents related to the event. Yet, an essential component of this kind of inquiry is the story of the inquiry itself, usually through the perspective of the researcher. Put another way, the researcher is seen as a participant, and in analysis as during the events being studied, the researcher's own perspective becomes important as it intersects with those of other players.

Much can be learned on this method from two recommended sources. Clandinin & Connelly wrote a chapter called, "Personal experience methods" in the *Handbook of Qualitative Research* (Denzin & Lincoln, 1994) that is done in narrative inquiry style, and is quite helpful. Too, Carter & Doyle produced a chapter called "Personal narrative and life history in learning to teach" in the *Handbook of Research on Teacher Education (2nd Ed.)* (Sikula, Buttery, & Guyton, Eds., 1996) that reviews literature from this methodological perspective and related to teacher development.

An example: Research in an urban middle school

I have been working with the instructional staff of an urban middle school in Columbus for about 4 years, off and on. Initially, one of the teachers had attended a summer course in which I gave a short presentation on reading & writing in math and science. She later approached her principal, Mr. E, an imposing and energetic Caucasian man, and suggested that I come to talk to the entire school faculty on this topic. The date was set for an afternoon in early November. While I was pleased to do so, I wondered what the impetus for this request was.

By the end of the presentation and ensuing question and answer period, I had my answer: the school staff had decided to try to improve proficiency scores by focusing on math and science for a year. I was the "kickoff" speaker, encouraging reading and writing in all areas, but also encouraging a kind of integrated thinking, where a teacher (or group of teachers) chooses to highlight the math and science that are naturally a part of Physical Education, for instance. During that nutrition unit, students bring in nutritional information on food labels, and calculate and discuss diets and the food pyramid. In science class, the different kinds of biologically important foods (fats, lipids, proteins, carbohydrates, and so forth) are discussed, and linked to the Physical Education experience.

Following the initial presentation, I was invited to monthly meetings of the science and math faculty, who met with the principals to discuss challenges, generate ideas, and try to support each other in delivering good instruction. During this time, I felt like an outsider to the process, but as I continued to attend meetings, began to understand the school culture a lot more. Here, I discovered, was a strong principal who was willing to push, prod, cajole, support....whatever it took to make the program work. The teaching staff was an interesting mix of old-timers and newcomers, with not much in between.

Initially in these meetings, I was a quiet observer. I learned that I could expect Mr. E to ask my opinion, in a rather formal manner, several times during each meeting. I learned to monitor the conversation, not take too many notes (as it seemed to make some of the teachers nervous), and to appeal to the teachers as I spoke in response. Finally, about the fourth meeting (in March), this pattern seemed to break down, with the teachers asking me questions directly. What emerged was a much more collegial and conversational relationship. While it was clear that I had been accepted by a subset of the teachers as a colleague, two other things were clear to me also: 1) others in the group still held me at the more formal, non-collegial level, and 2) Mr. E. had been removed from his central role as intermediary between us. I wondered what impact this would have in the long run, given that he was so strong and controlling. Yet my relationship with him, the science and math teachers, and the entire school staff seemed to warm and grow over the remainder of that year. I supervised field experience students in Winter Quarter, and this may have helped as well.

Fast forward two years. Mr. E had been promoted to the district office, and Mrs. O has become the principal. At first blush, she seemed to be the antithesis of Mr. E as a leader and in appearance. She is a trim and petite African American woman, an astute listener, and a quietly energetic speaker. When Mr. E was in the room, you knew it by his overt presence. When Mrs. O is in the room, you often don't know it until she speaks. And when she speaks, people want to listen. She is an astute and careful listener, and it became apparent to me that she is a consensus-builder.

Again I was called and asked to give a presentation, this time in response to low proficiency scores across the board. My response was more clear this time. I needed to know more specifically about what is going on, in order to make sense of the request. This time, the district had mandated a focus on reading and writing in all subject area classrooms, as a way to improve performance on the proficiency test. The idea was that, since the test challenged many students in reading, if the students were taught to read carefully and strategically in all areas, they would do better.

My analysis of the situation at the Middle School, based on my experiences in the past and my ongoing relationship with two teachers there, was that relatively few teachers worked to build a culture of reading and writing in their classrooms. Too many saw this as the purview of the language arts teachers. I generalized the problem as this: how could I teach the teachers to value and build such a culture in their classrooms? I called Mrs. O to discuss this issue.

Mrs. O agreed that this could be the problem, and was very accepting of my take on the situation. Where I had expected limitations and critique, there was none. She indicated full support for whatever I could do to help her staff. I asked about bringing another OSU professor on board (an expert in working with text in classrooms), and focusing on building this culture. She thought this was a great idea. As I hung up the phone, I had an uncomfortable feeling of having too much freedom. The risk was that we would entirely miss the boat in our presentation.

Next I spoke with Dr. G, a noted professor and colleague in Language Arts teacher education, who also has some interest in science teaching. He readily agreed to share the presentation. We met 3 times to plan the presentation, which was to be held during a staff development day in November. During this presentation, I spoke directly about building a culture in the classroom incrementally, and keeping it manageable for the teacher. I also focused on the need for formal and informal support systems to promote teacher change. I suggested forming working groups or teams, on a formal or informal basis, to help generate thoughts and work out problems. Dr. G followed with a presentation on working with texts, including those that the students had created. He presented what current research says to the middle school teacher, and related this to my presentation.

During this presentation, we noticed that the teachers seemed to be buying in to the need for change to a degree we'd not expected. In fact, Dr. G commented on what a "with it" staff it seemed to be. For me as a researcher with a long history with this faculty, I was at first startled by this observation. Yet, as I watched them interact, I saw many of those who had been reluctant participants years before, now as willing and energetic participants. Teachers were talking, explaining, generating ideas for how this new information would fit into their curricular plans. I remember feeling elated at their change of heart. I wondered how much it had to do with a shared history of several years together (as staff mobility had stabilized), and how much had to do with the leadership style of Mrs. O.

The staff and Mrs. O were very gracious in thanking Dr. G and me for our work with them. Before we left, we engaged them in a summative activity working towards action plans for their classrooms. During this activity, we saw that many of the teachers had appropriated our ideas well, and were in the business of reformulating curricular units and plans to make text-based interactions a part of their classrooms. We were heartened by this response.

A month later, I was requested to attend a faculty meeting during which the middle school faculty would see their proficiency test data from the previous year. The principal and a new Instructional Leadership Team [ILT] of four teachers from the school had been working with this data for a week or so, picking out areas of concern to discuss with the staff. They had found that most of their students did not even attempt to answer the open-ended questions on the proficiency test. The problem is that each of these open-ended questions, which ask for higher order thinking, counts as much as 3-5 other test items. Thus, the ILT strategy (later adopted by the entire district) was that if students attempted these, they might be able to get somewhere. I was asked to prepare a presentation focusing on what it would take to get students to try these questions.

My approach to this problem was an extension of my earlier thinking about building a classroom culture around textual interactions (including 'verbal texts'). I believed that the teachers also had to build cultures that supported inquiry, so that students would see activities such as generating ideas, predicting, extracting important information, establishing hierarchies of importance, summarizing, synthesizing, and posing questions as a regular part of what they did. I judged (based on my discussions with the ILT during a planning meeting) that few teachers engaged their students in these activities in the classroom, because 1) they didn't know how, 2) they were activities that could require much more teacher time, or 3) the teachers were afraid that they did not know all of the possible "answers" to open-ended kinds of activities and questions. So, in response, I planned a presentation on building these things into their existing classroom cultures.

When I arrived at the school, the ILT teachers began by presenting the data to the staff, and before long, the session became animated. I heard some teachers saying, "Just tell us what to do, and we'll do it," and others saying, "These kids have problems, and we just can't solve them all." It became clear to me, as I listened, that I was not going to connect with this audience unless I thought carefully about their mindsets. I made a judgment to suspend my prepared presentation, and to engage them in inquiry into the problem as they saw it. When it was my turn, I stood nervously before them and asked, "Why don't students try open-ended questions?" I asked each person to write down some reasons before talking to anyone else. Then I encouraged them to share their lists with each other at their tables, and to 'borrow' for their own lists if they wished.

Next, they reported out, as I recorded on a transparency, projected for the group. Here are their responses:

Why don't students try open-ended questions?

- It's hard to translate their answer (thoughts) into written words
- The language of the question is unfamiliar, so they won't even try.
- Pure laziness.
- No (immediate) consequences for leaving blanks.
- Fear of Testing
- Their opinions aren't valued, so why try?
- Difficulty sorting out the needed information from the question.
- Low self-esteem.
- Hard words derail them, both in terms of content and context
- They have poor handwriting skills and don't want to write.
- Lack of parental support and guidance for homework
- They're used to multiple choice, where the answers are all there. Providing your own answer is hard.
- They are unable to read the questions.

This is the point at which you, as reader, can engage in narrative inquiry. Begin by re-examining the list above. As you do, pay attention to your responses to each item: thoughts, ideas, experiences you've had, emotions, judgments. Make brief notes about these. Spend enough time with the list that you feel as though your responses have dwindled or solidified. The questions below may help you:

- What do you see here? (Categories, subsets, etc.)
- What responses do you have to what you see? What do your responses tell you? Or, How would you approach this set of problems with these teachers?

From this point, your research is guided by the rules governing research: as accurately as possible, represent the stories and the ways they interact. This means that you, as the researcher, are an integral part of the research. Here, you are not an "objective observer," but rather an inquiring participant who interrogates the data in order to represent each story well.

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On the Road to a National Dialogue: Standards-Based Education Reform – *Is this what we meant?*

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The term "educational reform" has evolved from a well-intentioned concept to a political catch phrase. The National Dialogue was created to provide a forum for participants to move beyond agendas, entrenched opinions, and polarized debate and to pursue common ground to ensure that we recognize a shared responsibility and commitment to being shareholders of our children's trust (Biemesderfer, 2001). The intent of this paper is to provide background on the forces that came together to begin the National Dialogue and to share the process by which the reader may participate if so inclined.

Background

A meeting between two people in an airport spawned a gathering in 1997 of several people from across the country to discuss education. This gathering met under the title of the McREL Think Tank and later became known as the World Café. The group included school superintendents, national and state level representatives, college professors, school administrators, community members, teachers, and Myron Kellnor-Rogers from the Berkana Institute. Over the next three years, Kellnor-Rogers guided this group through a self-defining process which takes advantage of systems thinking. Through the use of what Kellnor-Rogers referred to as a World Café form of dialogue, the group became a self-organizing system (Wheatley & Kellnor-Rogers, 1996). The Café allowed this group of diverse people to talk about issues they "needed" to talk about. Superintendents talked with teachers; community people spoke with college professors; and so on.

As the group gathered in its fourth year, the topics of standards-based education reform, accountability, and high-stakes testing emerged. Working from the viewpoint that schools are living systems, and somewhere within the system exists the solution to the system's problems (Wheatley, as cited in Biemesderfer, 2001), Kellnor-Rogers was able to guide the Caférs toward the realization that the solution to the standards issue could be accessed by this group. With that in mind, the Mid-continent Research for Educational Learning (McREL), in conjunction with the North Central Education Laboratory (NCREL), and the Berkana Institute set out on a joint mission to launch a national dialogue about standards-based education reform.

In November, 2000, a design team was formed to develop a process by which the National Dialogue would be introduced to the country. During the next six months various iterations of this team set its sights on a meeting to take place in Kansas City, MO, in April, 2001. Invited participants included politicians, business people, school board members, parents, superintendents, administrators, teachers and students (180-200 in all). Knowing that an organization will realize the results for which it was designed, intentional or unintentional (Wheatley & Kellnor-Rogers, 1996), effort was made to keep the design flexible so that the real solution could present itself. What follows is a brief description of the goals for the National Dialogue as described by Tim Waters (2001) during the 2001 McREL World Cafe, the ground rules for true dialogue, and questions posed to help people begin the journey.

Goals

We want people to:

- Recognize a shared responsibility and commitment to being shareholders of our children's trust,
- Talk with those they would not otherwise talk with,
- Consider ideas, views and information they would not otherwise consider, and
- Go forward with strategies and new tools to do things they would not otherwise do.

Why dialogue? Through the use of true dialogue, "the expectation is that participants will reach beyond any differences and disagreements toward a better understanding of how to improve education for all of our children." (Biemesderfer, 2001 p. 5) In order for dialogue to be effective there are certain ground rules to be observed. (Senge & Bohm, as cited in Biemesderfer, 2001).

Ground Rules for Dialogue

- All participants suspend their assumptions.
- All participants regard each other as colleagues.
- The facilitator holds the context.

Where do we begin? We begin with a few defining questions to consider, with regard to standards-based education.

Questions

- Is this what we meant?
- How did we get here?
- Where are we now?
- Where do we want to go?
- How do we get there?

Challenge

In his annual state of American education address, U.S. Secretary of Education Richard Riley stated that it is important to have "a mid-course review and analysis to make sure everybody understands what the standards movement is all about" (McREL, 2000, p. 2). McREL believes that the challenge of Secretary Riley is rooted in the following issues:

1. There is little agreement about what standards-based education looks like.
2. The push for high-stakes accountability tends to limit the scope of standards-based curriculum and instruction.
3. Alignment between standards, benchmarks, and assessment is not clear.
4. Teachers do not have access to high-quality resources aligned with local standards.
5. Assessment and record-keeping requirements for standards-based education place a burden on teachers.
6. More information is needed about how standards can help *all* students.
7. Cost of implementation and support of those costs needs to be addressed.

Getting Started

Because this needs to be a *national* dialogue, a website (http://www.nationaldialogue.org) has been set up to monitor and facilitate the process. It will provide ongoing access to information about upcoming events, as well as an electronic library of research and media reports about standards-based educational reform efforts (Biemesderfer, 2001). The reader is invited to visit the website for more information and further discussion of the implications of this effort.

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