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Invited Presentation

Use Biomedical Laboratories in Physics to Develop Student Reasoning

by
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Abstract

The results of the "intrinsic motivation for learning" work by Thomas Malone (1) can be combined with the "development of reasoning" work by Robert Karplus (2) to create introductory physics laboratories that feature biomedical applications of physics. This presentation will discuss the attributes of the work of Malone and Karplus and illustrate how they can work together to construct physics laboratories that encourage the development of reasoning by students as well as intrigue them with biomedical applications. A concrete example will be given in a six-week module "How Do We See Color?" that was developed as part of the Humanized Physics Project (3, 4).

(1) Malone, T.W. (1981). "Toward a Theory of Intrinsically Motivating Instruction", *Cognitive Science* ***4***, 333-369.
(2) Karplus, R. (1977). "Science Teaching and the Development of Reasoning", *Journal of Research in Science Teaching* ***14***(2), 169-175.
(3) Humanized Physics Project, supported by the National Science Foundation, NSF DUE grants 0088780 and 0088712. Project co-PIs, were Robert G. Fuller and Vicki L. Plano Clark, University of Nebraska – Lincoln; Nancy L. Beverly, Mercy College; Mark W. Plano Clark and Christopher D. Wentworth, Doane College; and Beth Ann Thacker, Texas Tech University.
(4) Humanized Physics website: http://doane.edu/hpp/

Presentation

I want to make a case of having two additional purposes for a physics course for biomedial students in addition to the mastery of physics content of value to them in their future careers.

I believe that the physics course is an excellent vehicle for the development of student reasoning. I also believe that the activities in the course can be designed to motivate the students to learn physics.

In this talk I want to discuss these two purposes and this describe the specific series of physics lessons that we developed with these two purposes in mind. These lessons were our first attempts at this and I hope you will borrow our materials and improve them to bring them closer to the goals that we had in mind.

First, the development of reasoning.

The framework we used to understand the development of reasoning is based on the work of Robert Karplus and Jean Piaget. There are two important aspects of their work that we try to keep in mind:

- The stages of development
- The process of self-regulation

The stages of development that are particularly relevant to college physics teaching are concrete operational and formal operational reasoning.

CHARACTERISTICS OF CONCRETE AND FORMAL OPERATIONAL REASONING

CONCRETE OPERATIONAL REASONING	FORMAL OPERATIONAL REASONING
Needs reference to familiar actions, objects, and observable properties.	Can reason with concepts, relationships, abstract properties, axioms, and theories; uses symbols to express ideas.

Uses concrete operational schemes: **Class inclusion.** An individual uses simple classifications and generalizations (e.g. all dogs are animals, only some animals are dogs.) **Conservation.** An individual applies conservation reasoning (e.g. if nothing is added or taken away, the amount, number, length, weight, etc. remains the same even though the appearance differs). **Serial Ordering.** An individual arranges a set of objects or data in serial order and establishes a one-to-one correspondence (e.g. the youngest plants have the smallest leaves). . Formal schemes are either not used, or used only partially, unsystematically, and only in familiar contexts.	Uses concrete operational schemes and **Combinatorial Reasoning.** An individual systematically considers all possible relations of experimental or theoretical conditions, even though some may not be realized in nature **Separation and Control of Variables.** In testing the validity of a relationship, an individual recognizes the necessity of taking into consideration all the known variables and designing a test that controls all variables but the one being investigated. **Proportional Reasoning.** The individual recognizes and interprets relationships in situations described by observable or abstract variables (e.g. the rate of diffusion of a molecule through a semi-permeable membrane is inversely proportional to the square root of its molecular weight.) **Probabilistic Reasoning.** An individual recognizes the fact that natural phenomena themselves are probabilistic in character, that any conclusions or explanatory model must involve probabilistic considerations, and that useful quantitative relationships can be derived, for example, the ratio of actual events to the total number possible. **Correlational Reasoning.** In spite of random fluctuations, an individual is able to recognize causes or relations in the phenomenon under study by comparing the number of confirming and disconfirming cases (e.g to establish a correlation of say, blond hair with blue eyes and brunette hair with brown eyes, the number of blue-eyed blonds and brown-eyed brunettes minus the number of brown-eyed blonds and blue-eyed brunettes is compared to the total number of subjects).
Needs step-by-step instructions in a lengthy procedure.	Can plan a lengthy procedure given certain overall goals and resources.
Limited awareness of one's own reasoning. May be oblivious to inconsistencies among various statements one makes, or contradictions with other known facts.	Is aware and critical of one's own reasoning; actively checks conclusions by appealing to other known information.

The mental schemes of concrete operational reasoning form the basis of the student's development of formal operational schemes. According to Piaget, the process of self-regulation is essential for the development of more adequate reasoning patterns. The motor that drives self-regulation is the biological need for equilibration, i.e. the harmony between reasoning and experience. Hence, the experience of disequilibration, when one's mental expectations are NOT matched by experience, drives one to more advanced reasoning patterns.

We found in this understanding of disequilibration as link to Malone's work on intrinsic motivation. In his work Malone identified three aspects of a learning experience that can make it intrinsically motivating. He labeled those three aspects as fantasy, challenge, and curiosity.

• **Fantasy**

An important aspect of learning is the theme, or story line. Physicists already use fantasy, e.g. point particles, friction-less planes. But our fantasies are seen as boring to our students.

As an example of using a storyline to motive students to learn physics, consider the historical narrative we wrote for our Tacoma Narrows Bridge videodisc. A portion of the video is accompanied by the first person narration of the newspaper reporter who drove his automobile onto the bridge in 1940.

"I saw the Tacoma Narrows Bridge die! And only by the grace of God escaped dying with it.

"I have been near death many times in my life, but not even in my worst experiences in France did I know the feeling of helpless horror that gripped me when I was trapped on the bridge this morning

"Those who stood on the shore and watched the bridge in its death agony can have no conception of the violence of movement felt by one out beyond the towers. Safely back at the toll plaza, I saw the bridge in its final collapse and saw my car plunge into the Narrows. With real tragedy, disaster and blasted dreams all around me, I believe that right at this minute what appalls me most is that within a few hours I must tell my daughter that her dog is dead when I might have saved him."

I believe that storyline has the kind of fantasy and emotion that many of the students in our physics courses find appealing. They begin to believe that physics has, in fact, some relationship to these kinds of everyday events. From my point-of-view, I cannot emphasize enough that we, as a community of physics educators, have not been creative enough in developing physics stories to engage and motivate students.

Fantasy makes instructional environments more interesting and more educational. A good fantasy can help learners apply old knowledge to new situations and by provoking vivid images a good fantasy can help learners remember better. We are fortunate in physics. We have a wide variety of visual images from which to select that can be interesting to our students. Consider the high speed film clip of the cat drop shown on the Physics Vignettes videodisc. How does a cat manage to turn over and land on its feet? How could a person, suspended right side up over a swimming pool, drop and rotate to go into the pool head first? We showed such events on our Studies in Motion videodisc.

I submit that this kind of visual imagery, this kind of discussion about these kinds of observations, and the opportunity to take students to a swimming pool and drop them in it, will provide student interest in physics that we usually do not get. Hypermedia can also enable us to offer physics stories where different students can choose, or be offered, different fantasies.

• **Challenge**

Intrinsically motivating instruction challenges the learners. A challenging environment provides goals whose attainment is uncertain. A good goal is personally meaningful for the learners to achieve. Such goals use the skills that the learners are being taught. Frequently such a goal is part of a fantasy that we construct for the learners. The good goal allows the learners to have a sense of power, once they have accomplished it, that they can do more. Its attainment enables the learners to perform new projects. Hypermedia, I argue, provides us with with some wonderful new approaches to this aspect of intrinsically motivating instruction. Hypermedia enables us to provide goals with variable difficulty, randomness and multiple levels.

We can use hypermedia to hide information. Almost no one who writes about computer-based instruction writes about the power of the computer to hide things. You can not hide anything in a book. We are safe because the students do not read them. But the answers to the questions are in there if they look. You can fix a hypermedia program so that if will not show students the information they need if they do not have enough sense to know to ask for it. Isn't it partly the hiddeness of nature that got us hooked on physics? Now we can provide an opportunity for that same kind of surprise and Ah-Ha experiences for our physics students through the proper use of hypermedia.

An appropriate challenge is captivating because it engages a learner's self-esteem. It is very important for us to understand that our students should have higher self-esteem at the end of our physics courses than at the beginning. Too often I hear stories about physics learning experiences, from introductory level through graduate oral exams, that tell about how depressed the students are at the end. That is not an appropriate function of our task as educators. Our students should be empowered and have positive self-esteem when they finish our physics courses.

One of the ways we do that is to challenge our students to use physics to think about everyday events. One of the ways to do that is to show such things as gymnastics events, as illustrated on the ***Studies in Motion*** videodisc and on the ***Understanding Human Motion*** CD, and discuss the applications of physics to them. You can show such activities as an aerial walkover or a power lift. Step through each event a single frame at a time, seeing it every thirtieth of a second, and discuss the location of the center of mass of the gymnast in each frame

• **Curiosity**

Human beings are naturally curious. A learning task needs to provide an optimal level of informational complexity for us, as learners, to be attracted to it. If a task is too simple we are not interested. It should be surprising and novel, but not completely incomprehensible. Human beings are made curious by both sensory stimuli and cognitive stimuli. Hypermedia with images and sound allows us to provide both of these. For example, ask your students to consider what happens to a cyclist who discovers a car door is suddenly opened in front of her as illustrated in the chapter on braking on the ***Energy Transformations Featuring The Bicycle*** videodisc.

Hypermedia needs to present just enough information to make learners existing knowledge seem to be incomplete, inconsistent, or unparsimonious. Then natural human curiosity helps to motivate them to learn more.

The Karplus Learning Cycle

While trying to develop classroom materials that both motivate students and encourage them to develop more mature reasoning patterns. We tried to incorporate the concepts of Malone into Karplus Learning Cycles.

Robert Karplus had developed elementary school science classroom materials intended to use science concepts to enhance the reasoning of elementary school children by using a classroom strategy he called a Learning Cycle. We have taken Karplus's ideas and modified them for use with college students. Our version of the Karplus Learning Cycle has three phases, Exploration, Invention and Application. This approach is very similar, I think, to the Modeling Workshops taught at Arizona State University, the Guided Design materials in engineering education and the Cognitive Acceleration in Science Education (CASE) materials in the UK.

- ***EXPLORATION*** - Following a brief statement of topic and direction, students are encouraged to learn through their own experience. Activities are supplied or suggested by the instructor which will help the students to recall (and share) past concrete experiences and to assimilate new "hands-on", "eyes-on" experiences helpful for later ***INVENTION*** and/or ***APPLICATION*** activities. During ***EXPLORATION*** the students receive only minimal guidance from their instructor and examine new ideas in a spontaneous fashion.

Emphasis - "hands-on", "eyes-on" experiences with familiar objects and systems.

Focus - Open-ended student activity

Function - Student experience is joined with appropriate environmental options not previously considered by the student.

1. This phase of the ***Learning Cycle*** provides students with reinforcement of previous "hands-on", "eyes-on" experiences and/or introduces them to new "hands-on", "eyes-on" experiences to be related to the later ***INVENTION*** phase.
2. ***EXPLORATION*** allows for open-ended considerations, encouraging students to use concrete experiences to consider new ideas.
3. During ***EXPLORATION*** the instructor supplies encouragement, provides challenges, asks questions, and suggests alternatives. The instructor should encourage students to try a variety of experiments.
4. Student behavior during ***EXPLORATION*** provides information for the teacher about the student's ability to deal with the concepts and/or skills being introduced. The students will reveal the reasoning skills which they evoke in search for the solution to a problem.

Questioning Skills and Strategies - Open-ended questions are asked to broaden an area of study by generating multiple possibilities. The instructor uses extended wait-time, i.e. the time one waits for students to give a response to a question one has asked, e.g. quietly count to 10, and may even expect no answer at all. {"Wait Time: Slowing Down May Be A Way of Speeding Up!" Mary Budd Rowe, Journal of Teacher Education, Vol. 37, No. 1, 43-50 (1986)}

- ***INVENTION*** - In this phase the "hands-on", "eyes-on" experiences of the ***EXPLORATION*** are used as the basis for generalizing a concept or for inventing a principle. Student and instructor roles in this activity may vary depending upon the nature of the content. Generally, students are asked to invent the relationship for themselves with the instructor supplying encouragement and challenges when needed. This procedure allows the students to gain confidence with the conceptions they have invented. This confidence comes from the fact that they have tested possibilities and kept those features that enabled concepts to fit with the experiences.

Emphasis - Generalization of "hands-on", "eyes-on" experiences and ***INVENTION*** of hypothetical possibilities.

Focus - Student's active involvement with instructor for generalization.

Function - Students become familiar with generalized concepts and/or skills. During this time students are encouraged to formulate relationships which generalize their new ideas and concrete experiences.

Questioning Skills and Strategies - Focusing and valuing questions are asked to encourage the transformation of information and the determination of appropriateness of results. Such questions require a long wait time, perhaps 5 seconds or more. Some direct information questions are usually asked so that factual information can be broadly shared.

- ***APPLICATION*** - The ***APPLICATION*** phase allows each student an opportunity to directly apply the concepts or skills learned during the ***INVENTION*** activities. ***APPLICATION*** provides the students with additional broadening experiences. They use the invented concepts in different specific settings. The ***Learning Cycle*** allows each student the opportunity to think for one's self. The instructor is present as an overseer of the activity. Yet the instructor must guard against overplaying the role as director and facilitator. The instructor must provide an open classroom atmosphere within a well-defined boundary.

Emphasis - Relevant use of generalized concepts and/or skills.
Focus - Directed student activity
Function - Further use of generalized concepts in other systems.

1. To begin the ***APPLICATION***, the students and the instructor may interact in planning an activity for applying the invented concept and/or skill. The activity should provide a new or unique concrete situation.
2. Students are asked to complete the designed activity to the satisfaction of the instructor. The activities should provide further experience which will act as broadening and stabilizing experiences related to the new skills or concepts.

Questioning Skills and Strategies - Goal-oriented questions are asked that may require directed activity on the part of the students. These are questions that may set the students to work on a common task.

Combining Karplus and Malone

It seems clear to me as we consider how to combine the insights from the work of Karplus and Malone that we need to develop courses in, what Kirby Urner has called, First Person Physics. The focus of our courses needs to shift from being a physics content autocracy to being a humanized approach to physics. I want to mention two different ways we might be able to achieve First Person Physics courses.

1) Buckminster Fuller's "energy slave" approach.

Buckminster Fuller developed the energy unit of the "energy slave." Bucky's measure of the standard of living in turn is based upon calculations he did in the February 1940 *Fortune* magazine on per capita energy consumption in an entire economy. Energy can be measured in foot-pounds, the amount of work required to lift one pound one foot. Fuller invented a larger unit called an "energy slave", which is the amount of work one man could do for eight hours a day during one year: thirty-seven and a half million foot-pounds per year. (37,500,000 ft-lb = 14.12 kWh) {Bucky assumed 150,000 foot-pounds of work per day and working 250 days per year. That's 0.0565 kWh per day, or 14.1 kWh in a year.}

Fuller computed the total energy (in foot-pounds) consumed per year by all machinery of a given economy, then deducted 96% for inefficiency, and then divided by 37 1/2 million to get the total number of "energy slaves" available to that economy for one year. If you divide the human population into the number of energy slaves, then of course you have the per-capita energy slaves for one country for one year. With that yardstick, Fuller found in 1940 that each person in the U.S.A. had 153 energy slaves, a number then far exceeding any other country in the world except Canada.

Fuller made an assumption: in a weaponless economy, a family of five could be maintained at a high standard of living with only 100 energy slaves working for them (mostly in the economy at large, not just their home). Thus, even in 1940, an American

family of five had a theoretic 765 energy slaves to their credit, but most of them were being diverted into weapons production, and energy was unevenly concentrated in a few regions.

As Fuller read the trends, the current speed of world industrialization and of "doing more with less" was enough to make everyone on earth economically successful willy-nilly within 30 years, merely as the accidental result of tooling and technology coming from the arms race. If we applied our efforts directly to the proposition of "making the world work", the same job could be accomplished in as little as ten years.

Using energy use numbers for 2007, following Fuller's calculations, each person in the USA now has 256 energy slaves. So each of us has the equivalent of 256 people working for us to do our jobs and daily lifestyle tasks. A USA family of five has 1280 energy slaves.

2) Concentrate on human body physics

Specific Example

How Do You See Colors?
(Light and Optics - Module LO)
(Six weeks)

Background:

The module was taught in a three lecture, one recitation, one laboratory class per week format. The laboratories all came after the first two lectures of the week and the recitation. So in the first week there were only three class periods before the first laboratory class. After that there were four class periods between each laboratory class.

LO1: From Where Does Light Come?	
Lecture - LO1-Lec1	Explore some color vision and optical illusions using overheads Try to set up the question - How do we see colors? Introduce the source, medium and detector model for studying this question. What is light anyway? Darken the lecture hall and allowed the students to develop their night vision. Use a photoelectric demonstration.
Recitation - LO1-Rec1	Do the Kepler reasoning task. Do a human sized spectra activity which leads to the invention of the concept that deviation of light by a grating, or a prism, is inverse with energy of the light
Lecture - LO1-Lec2	Started with classical E&M field and showed the total E&M spectrum and the very small region of visible light in the whole thing. Using $\lambda f = c$ relationship showed that $E=hc/\lambda$. Did that calculation for 550 nm light, which is the peak sensitivity for a typical human being. The answer of about two electron volts is then discussed as the order of magnitude for optical processes. Compared this to thermal processes (room temperature is only about 0.02 eV) and chemical processes which are typically tenths of an eV. Showed

	a dim incandescent light bulb and turned it up bright to show that even as a bright light it would not discharge the electrometer. Showed Planck's law fit to the data. Did the Photoelectric demo again and showed the influence of glass on the UV light source…light as photons. Showed the three gas tube spectra and distributed good diffraction gratings for them to use to look at the spectra. Then showed the Balmer series and discussed the Balmer guessing the number bit, gave the Balmer equation.
Laboratories- LO1-Lab1	***Lab #LO1 - Making Light and Detecting Light*** • Compare responses of two different optical detectors (human eyes and Pasco light sensor) • Compare output of two different light sources (Incandescent source and the Hg gas tube) • Use spectrophotometer with prism to study composition of light sources by measuring light intensity vs. angle.
LO2: How Does Light Get to Your Eyes?	
Lecture - LO2-Lec1	Lecture Quiz – 1 - About spectra, comparing photodiode output and human vision response curve. Showed a Hg spectra and then handed out the fill in the blanks of the hydrogen spectra activity. Collected some results then did a quick over view of Bohr's work and gave the result: $\Delta E = -13.6 eV/n^2 . (1/m^2 - 1/n^2)$. They were asked to compute the n value for their missing data piece. Read textbook section on the Bohr atom.
Lecture - LO2-Lec2	Handed out Hydrogen spectra homework, due the next day in recitation. Florescent and Phosphorscent Sources and Hg spectra demo. Showed diffraction grating equation.
Recitations - LO2-Rec1	Discussed the quiz on spectra.source function times response function = output function. Light intensity on Venus questionnaire, How does light get to our eyes? Transmission . Inverse Square Law activity.
Lecture - LO2-Lec3	Did the 27 different group activities..three light sources, three response functions(photodiode, human eye, photomultiplier). .compute the missing one. Source- medium - output model
Laboratories- LO2	***Lab #LO2 - Sunglasses and Other Optical Filters***

	• Introduce optical density by examining effect of a pair of sunglasses as measured by eyes and different light detectors • Study effect of different colored filters • Study the absorption of light by multiple layers of colored filters. Model absorption data with an exponential decay function.
LO3: How Does the Medium Change What You See?	
Lecture – LO3-Lec1	Lecture Quiz – 2 Erythema & Inverse Square Law of Radiation Introduced transmission, absorption and reflection.
Recitations – LO3-Rec1	Discussed Erythema quiz Absorption quiz Absorption activity (Solar Filters)
Lecture – LO3-Lec2	Intensity --Review inverse square law…source, media, detector model Absorption using filters and photometer-Bouguer's Law, exponential modeling. Color filter data. Properties of exponential functions. Discuss Optical Density(O.D.)
Laboratories-LO3	***Lab #LO3 - What Color of Light Do You See?*** • Color response of the human eye • Wavelength dependence of the absorption of light by different color filters • Use spectrophotometer with prism and light detector to study the transmission and optical density of different color filters as a function of wavelength
LO4: How Can You Use Light to Measure Other Properties?	
Lecture – LO4-Lec1	Lecture Quiz – 3 Optical Density Polarization and Doppler Effect Took detailed data for polarizers as function of angle…got good data. Showed Chap. 27, Side C of Cinema Classics. Doppler Effect for Sound. Assigned Reflection for Monday
Lecture – LO4-Lec2	Reviewed Optical Density, Doppler Effect {solved the red to green problem}, Polarization, Compared in class data to cosine squared law…pretty good agreement! Started a discussion of reflection…used laser and plane mirrors, angle of incidence = angle of reflection…the images are virtual and equidistance from the mirror. Assigned curved mirrors as reading for next class.

Recitations – LO4-Rec1	100 W light bulb quiz…compute distance for reading and for warehouse lighting. What effects would you expect from other stuff in the room? Complete absorption activity
Lecture - LO4-Lec3	Blackboard optics to demonstrate the properties of spherical mirrors. Introduce the concept of refraction
Laboratories- LO4	***Lab #LO4- Is that Product Safe?*** • Using a colorimeter to study transmission and absorption of fluid samples with different concentrations of red additive • Study linear relation between optical density and concentration • Determine the unknown concentration of a fluid sample
LO5: How Does Your Eye Form Images?	
Lecture – LO5-Lec1	Lecture Quiz – 4 - Beer's Law Quiz Snell's law and thin lenses Refraction Notes-dispersion, lens aberrations Assign Chap. 27, sections 1, 5-7
Lecture - LO5-Lec2	Interference, Linear Superposition Double Slit, Single Slit Diffraction Grating: $d \sin\theta = n\lambda$ Circular Aperture: $d \sin\theta = 1.22\lambda$
Recitations – LO5-Rec1	Optical Density vs. time forensic pathology question Lens exploration activity began
Lecture - LO5-Lec3	Assigned wavelength HW from lab data Study human eye as an optical instrument Assigned words related to human vision
Laboratories- LO5	***Lab #LO5 - How are images formed from light?*** • Study reflection of plane mirrors • Study refraction with acrylic block • Study how and where images are formed by plane mirrors and lenses
LO6: How Does Your Brain Understand Colors?	
Lecture – LO6-Lec1	Lecture Quiz 5 - concave mirror, convex lens, concave lens…based on ID numbers. Discussion human eye functions and showed various human eye data.
Lecture - LO6-Lec2	Discussed The Amazing Eye handout…field of vision

	Retina, Rods and Cones, distribution and spectral response
Recitations – LO6-Rec1	Oral Reports on Color Vision Handed in their research papers.
Lecture - LO6-Lec3	Final Summary of Color Vision…discussed three theories of color vision and scientific reasoning falsification versus verification. Trichromatic model, Opposite color model, Zone model
Laboratories-LO6	***Lab #LO6 - The Amazing Human Eye*** • Assess characteristics of one's own eyes (visual accuity, near point, blind spot, and astigmatism) • Model the focusing behavior of the human eye with Cenco eye model • Model and correct various common eye defects
Exam over How Do You See Colors?	

Conclusion

We have tried to bring together our understanding of cognitive development, of motivational psychology and of the biomedical applications of physics to create a first person physics course that will capture the attention of students and enable them to grow intellectually while mastering physics concepts that will be of use to them in the life after graduation from college. Our work is just a very primitive beginning. Please join us in this task. Use our efforts to shape and enhance your own work. Feel free to build upon our work. Let us use biomedical laboratories to develop student reasoning.

Our materials are available on our Humanized Physics Website –

http://doane.edu/hpp/

References:

A collection of the works of Robert Karplus:
A Love of Discovery: Science Education, the Second Career of Robert Karplus (Innovations in Science Education and Technology) edited by Robert G. Fuller. ©2002, Springer USA, New York. ISBN13: 9780306466878; ISBN10: 0306466872.

The relevance of the work of Robert Karplus and Jean Piaget for college teachers:
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