DOCUMENT RESUME

ED 403 135 SE 059 598

AUTHOR	Pelaez, Nancy; And Others
TITLE	Engagement, Wonder, and Learning by Jerks in Science: Perspectives of Pre-Service Elementary Education Students, Medical Students, and Research Science Doctoral Students.
PUB DATE	10 Jan 97
NOTE	12p.; Paper presented at the Annual Meeting of the Association of Educators of Teachers of Science (Cincinnati, OH, January 10, 1997).
PUB TYPE	Reports - General (140) -- Speeches/Conference Papers (150)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Cognitive Development; Educational Strategies; Elementary Secondary Education; Higher Education; *Learning Processes; *Learning Theories; *Science Education; *Student Attitudes

ABSTRACT

How do good science students perceive the process of learning science? What occurs in the learning process that motivates students to accept the challenge of pursuing a career in science? This paper reports on panel discussions held by teams of medical students, research science doctoral students, science education students, and high school chemistry students who described themselves as good science learners. The students discussed what part of science learning is acquiring knowledge, what part is scientific method, and whether learning difficult scientific concepts occurs as a gradual process or in quantum leaps. Conversations were transcribed and responses classified to identify consensus or unifying themes. One conclusion made is that good science learning involves an emotional process beginning with frustration at not understanding a given concept. Good students use frustration to focus their attention to work through the concept, sometimes through repetition using different perspectives, until a broader general meaning within a context becomes clear. Understanding in science comes in jerks, sometimes in a flash of insight, and is accompanied by feelings of elation. The breadth-rather-than-depth approach currently used in teaching science in schools rarely allows students the opportunity to experience this process. (PVD)

Engagement, Wonder, and Learning by Jerks in Science

by
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ENGAGEMENT, WONDER, AND *LEARNING BY JERKS* IN SCIENCE: PERSPECTIVES OF PRE-SERVICE ELEMENTARY EDUCATION STUDENTS, MEDICAL STUDENTS, AND RESEARCH SCIENCE DOCTORAL STUDENTS

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INTRODUCTION

In the introduction to his book, *Flow*, Csikszentmihalyi (1990) suggests that our most enjoyable experiences occur when a person's mind is stretched to its limits in a voluntary effort to accomplish something difficult and worthwhile. The process is never easy and can be definitely painful, but in the long run, a sense of mastery results in an experience of elation.

Science has often been represented as a cold subject with little emotional context. Yet basic research science doctoral students and medical students are passionately engaged in science. *How do good science students perceive the process of learning science?* What occurs in *the learning process that motivates students* to accept the challenge of pursuing a career in science? This paper will report on panel discussions held by teams of medical students, research science doctoral students, science education students, and high school chemistry students who were asked to describe themselves as "good" science learners. The perception of students regarding methods that motivate, improve attitudes, and increase the cognitive level to strive for excellence in the sciences should be our starting point as we look for ways to communicate science concepts effectively. How do the questions raised by the students relate to the AAAS Science Benchmarks (1993) and the NRC Science Content Standards (1996)? Should we place more emphasis on "understanding scientific concepts, developing abilities of inquiry, and studying a few fundamental science concepts as opposed to covering many science topics" as recommended by the National Research Council?

RESEARCH PLAN AND SUBJECT SELECTION

Small group panels made up of 2 medical students, 2 doctoral students, and 2 science education students discussed what part of science learning is acquiring knowledge, what part is scientific method, and whether learning difficult scientific concepts occurs as a gradual process or in quantum leaps. Currently enrolled student volunteers were recruited from medical school and upper level science education classes. Conversations were compared with small groups discussions among high school chemistry students. Student volunteers were selected for both race and gender balance. Conversations were audiotaped. The topic was introduced and conversations guided to stay on the topic using the following questions:

What was the hardest thing you learned in science and how did you approach that problem?

What makes a "smart" science student?

What motivates you to learn science? What gets in the way?

How do you know when you've learned something in science?

Take a moment to recall the very best science learner you've ever known. What approaches to learning science set that learner apart? Now recall the very opposite - someone who really struggled with science. Describe that student in action.

PROCEDURES FOR DATA ANALYSIS

Conversations were transcribed and responses classified to identify consensus or unifying themes among ideas. Discussion of students' responses will focus on how the questions raised relate to the AAAS (1993) and NRC (1996) guidelines pertaining to the nature of science and science learning.

RESULTS

Let us begin with the concluding words of a basic research science doctoral student. It was interesting to note that despite the diversity of the groups, there was a strong sense of sharing common ideas and thoughts about the science learning process.

> "We are all saying basically the same thing. We all went through similar processes to get to where we are now ... We all went through a similar actual process of learning. Schools may differ, but people are the same. It's more the person, not necessarily the school. Sure we were all educated differently, you know, depending on the school, public, private, or whatever. However, we all had to learn and that is a personal thing and not something a particular school does."

Below, we have listed statements which summarize some of the consensus ideas among the students who participated in our conversations.

Many statements associate science learning situations with negative emotions:
A medical student remembers struggling with Physical Chemistry;

> "It was a struggle for me and it became an unpleasant experience because I don't feel I have a firm base even yet. In some cases it's a matter of simple memorization. It's not a matter of necessary comprehension. You have to get through the course and you decide, boy, I'll never do anything that involves this type of science!"

There is wide agreement that learning new terms is hard and provides no intrinsic motivation.
A sophomore Chemistry student says

> "Science is hard and science is boring, especially those terms you have to remember, like in Biology, what's a biome."

A medical student agrees:

> "All the vocabulary was new. I had no orientation at all, so it was looking at something that was completely foreign... The most difficult things about science in general for me is just getting myself to memorize facts. It's just difficult to get motivated to memorize anything."

In another case

> "They even had a lecture based on vocabulary, but we walked out of it not knowing a single vocabulary word."

How, then, do we motivate and focus attention? At all levels, students mentioned science topics that aren't learned the first time through.
Advanced Chemistry students discuss learning stoichiometry:

> "It wasn't successful the first time he taught it, so the teacher thought it was the way he taught it so we went back and did it again. Going over it more than once did help. Maybe he was a little bit clearer the second time. Maybe he thought we understood more than we did the first time, so the second time he broke it down and went over every little detail."

> "The teacher presents it, but then you have to take it upon yourself, whether it be by yourself or with someone else helping you, it's up to you. If you don't spend a lot of time on your own, trying to get it, you don't get it."

> "When you're interested and you want to know, you just keep trying until you get it and that makes a good learner. A lot of times you don't get an answer right away. If you're interested you don't give up as quick."

All students mentioned repetition as a component for learning science, but there was discord about whether or not it was effective. According to an advanced Chemistry high school student

> "You get a little bit every time that you go over it. That little bit you get each time keeps on mounting up and just all at once you get it! Repetition does help."

Repetition was more than just repeating the same thing over and over, though. Several medical students mentioned the fact that they learned different aspects each time.

> "We see any process that we study related to everything else that we've had... It's all just lists of facts, but you encounter each more than once and you see it from many different angles, so you end up learning a lot more than you think you have, just by seeing it more than once and in different ways."

Another medical student found it useful to repeat, but in different ways.

> "What really works best for me is if I can hear it and see it and write it. I go to class and hear it, read it in a book, and write out what I learn. First I write down only the bare skeleton of what I know and each time I go back over it, I fill in more details."

Some of the comments regarding repetition were associated with negative emotions. According to one medical student

> "Just to sit and force myself to do those reactions over and over again was horrible. Yet doing the reactions was simple. Repeating over and over again works well for me."

One research science doctoral student says

> "I like the active research and discovery. I get to do that. Another thing with research is the "re-" part, that is, repeating, repeating, repeating, which is annoying, but that's a whole other subject. I just think that drive of wanting to learn has me in science as opposed to other fields."

Not all students agreed with the value of repetition. In the words of an MD/Ph.D. student

> "They're saying, well, this is all you need to know, and in the other class they say this is all you need to know and you just touch on it a little bit every time, but you miss out. In that same amount of time, if they had just combined it all together... it would have made more sense."

Sometimes results were not necessarily attributed to repetition, such as with this medical student:

> "Truly I don't believe that having previously had the course helped. It wasn't that repeating the material helped, it was more my habits or my attitude..."

Pleasureable emotions associated with science learning were expresses by many students. Statements revealing pleasure or delight in science reflect a period of stagnation, a feeling of getting stuck, and then, "aha!", sudden insight! Valuable and enduring science learning was suggested to be a result of such learning by jerks.

A sophomore Chemistry student says

> "We had to convert grams to moles and I just couldn't get it. I was just lost for the most part, but when I finally got it, everything just came all at once."

An advanced high school Chemistry student agrees:

"Sometimes, something hits you in the head, and you say, oh, yeah, I've learned it now! And once I've learned it, I've really learned it."

And a medical student and a graduate student agree:

"I think learning goes in jumps. I'll find myself reading something for the third or fourth time and all of a sudden the light bulb will come on - and it just makes sense."

"Bam! And it makes your day.... It's so cool!"

At first, an education student thought science students learn gradually along the lines of the curriculum, yet found jumps when learning to become a science educator:

"I've had jumps in my academic career just because it's an "aaah, now finally everything means something and I can make the connection just because I understand." That comes in the form of a jump."

Less successful high school Chemistry students give up when confronted with feelings of discomfort. A sophomore Chemistry student says

"Reading the book is fundamental, but sometimes the book just doesn't explain very well. Sometimes you do the assignments and look at the back of the book to see if your answer is right. If my answer isn't right, I just give up, because I just get too tired to keep on trying."

An advanced Chemistry student agrees.

"Some people might lose their confidence. They get a bad grade and ... so they just forget about it ... instead of sticking it out and trying to finish."

Some students admit that good science learning would not occur without the jumps and accompanying discomfort. According to an advanced high school Chemistry student

"I don't think there's going to be too many things from now on that I'm going to learn that I'm not going to feel frustrated at some time."

Indeed, the intrinsic motivation advanced science students find in science may actually be to overcome the confusion in order to eliminate feelings of discomfort. In the words of a medical student

"You don't always know what wonderful application something new in science is going to have... so it keeps you thinking one step ahead to try to figure out what's going to happen next. It almost feeds upon itself. There's an inherent interest because of these undefined problems."

Along with the emotions involved with learning, many students pointed to the relevance of the material as a key for engagement. As they learn students become aware of the relevance of information. Students at all levels agree that true learning implies understanding within a meaningful context:

A sophomore Chemistry student says

"I learned how to understand the periodic table...to work with it we just used it .. [and we learned] what everything meant."

An advanced Chemistry student clarifies this further:

"You really learn it when you can see the big picture, everything else that's involved, what's meaningful about it. Sometimes you just do the one thing and you don't understand what's really involved."

A medical student studies by looking for relevance.

"I look at my notes, I look at everything and ask myself, what's important here, and why is it important?"

Another medical student focused on evaluating importance by fitting facts into a context.

"As to whether too many facts can get in the way, I don't believe they do. The key there is how to use your facts. Too much knowledge would never be harmful. Not knowing what is important and what is not important is the problem... You don't know how important some facts are and you have to find out before you can act."

And a graduate research doctoral student uses problems to identify the context.

"I found those homework problems were what I needed to try to understand and figure out how I was supposed to use this information. It was a matter of understanding the context..."

An education student agrees with the importance of context to learning.

"If I am struggling with a difficult concept, it does help to put it in a context where you feel like if you can grasp this and fully understand this context, it's going to mean something to you."

Another education student agrees:

"That's the meaningfulness of the engagement. It's almost like learning all these different concepts in the air, and once you make a connection, you can actually grab it, you can make it part of your own knowledge and present it as part of your own concept.'

Understanding the relevance of a context was actually a motivating factor in the words of this medical student:

"I am to the point now that I can see what is important and how it's relevant, and so because of that I have a better understanding of why I need this information and why it's important to me..."

Various students recommend an introductory framework in order to tie together relevant new facts.

"You have to have a scaffolding first. You can't put tinsel on the tree without the branches."

Good science students endure the discomfort and, indeed, use such opportunities to identify and work on opportunities for learning.

Advanced high school Chemistry students seem prepared for this

"I don't think you can learn something like stoichiometry without going through a period of frustration. A teacher can't explain it so well that you get it the first time."

A graduate doctoral research student looks forward to the discomfort.

"My mentor will ask me a hard question. Sometimes I know and sometimes I don't. And I love that, because I find out if I don't know and then I can run over and look it up. I hate making an ass of myself... If you're a person that doesn't like that, you'll try not to let it happen again, so then you'll go and read a bunch of articles so that next time you'll know more..."

One major difference between high school and graduate students was the need graduate science students expressed for learning to think. In the words of research doctoral students

"The hardest thing I had to learn in science was how to think. It had absolutely nothing to do with things I had to memorize or book learning or anything I learned in class because how to think wasn't taught in any class... Class work doesn't facilitate what you do in the lab. Nothing prepared me for that. There is a big difference between learning in a classroom and the lab because in a classroom you have to memorize things...[In the lab] you have to pull things together and think about what it is that you're learning. Very rarely did ... you ... use your brain in a creative way in a class."

A medical student points out that the only way to learn to think through new problems is by getting practice solving problems.

"The hardest thing I had to learn was [how to] approach undefined problems... because my background didn't have much of that. If you do your homework problems, that doesn't necessarily prepare you for problems down the road. It does in the way that you learn how solve problems, how to attack problems, but it doesn't mean that every single time that I follow steps one two three and four in sequence that I'll get the right answer. Each time and each case, you're developing problem solving skills in general, and not necessarily a set pattern that can be singled out to give the right answer."

Research doctoral and medical students agree that learning is better with problem-based situations that provide the opportunity to think, and this seems to be due to intrinsic motivation which goes along with such problem-based learning. The emotional difference between thought-provoking learning and memorizing is apparent in the words of a doctoral student:

"When you suddenly do have motivation, for example, with problem-based learning, then it's really cool... you want to go look up articles and go back to your textbook and look up those pieces of information that you may have missed the first time around. I believe that all of this would be a lot easier if they would just get into that kind of fun stuff sooner... Just memorizing the facts is horrifically boring."

A medical student agrees, but points out that problem-based learning is too time consuming for the demands of medical school.

"With problem based learning, we did learn better, much more thoroughly and I understood even better. It was definitely a better way to learn, but I didn't learn enough to merit putting six hour into it. In six hours, hating the memorization, I would have learned at least ten times as much material."

Because of the "stuck" periods, good science learning seems to require minds-on engagement by the students. An education student explains

"If you can't be engaged and feel a connection, then you're behind already."

And an education student describes favorably his feelings when he masters a concept.

"The jumps are more beneficial because that revelation fosters self-knowledge. It fosters that student searching for more knowledge because they've just had this marvelous revelation and there are questions that come with this revelation that maybe that teacher didn't prepare. It engages the student."

In conclusion, how do good science students learn? A good summary might be the method a graduate research doctoral student uses to study.

"What I ended up doing was looking and trying to figure out what made sense. First I would do the things that I liked, verbalize and try to explain what made sense. I'd read through the notes and one by one I'd check things off. That's obvious, and that's obvious - so I'd check off the things I could just guess at. When I got to something that I couldn't guess at, something that didn't make sense, then I'd stop to look at it. And if there was a formula, I'd try to derive it. That would take a little more time, but usually by the time I derived it, it would make sense and become obvious."

What then is the role of the science teacher? Here is the view of one science education student:

> "The most wonder must come from the educator. Students may not be either for or against a knowledge set, so it's the teachers sense of wonder that can communicate a positive sense or a negative sense until the revelation hits."

CONCLUSION AND FUTURE DIRECTIONS

In summary, feelings are a powerful influence on reason. We are possessed with a passion for reason, and those who choose to pursue careers in science and medicine are passionate about learning science. Good science learning involves an emotional process beginning with frustration at not understanding a given concept. Good students use frustration to focus their attention to work through the concept, sometimes through repetition using different perspectives, until a broader general meaning within a context becomes clear. Understanding in science comes in jerks, something of an "aha!" experience along with feelings of elation.

Emotions and feelings are involved in eliminating unrealistic options so that the total number of alternatives to contemplate in generating goals and plans is reduced. In this way, mental time and energy is focused on evaluation of a more limited set of viable options. Creativity, at least in science, does not merely consist of inventing new combinations, since that would result in an infinite number of mainly useless combinations. Creativity consists of making that small minority of useful combinations, and so the creative process can be described as a process of discernment or choice.

A hypothesis proposed by Damasio in his book, *Descartes' Error: Emotion, Reason, and the Human Brain* (1994), suggests that emotions and feelings are manifestations of drives that are central to scientific rationality, specifically, to valuing alternatives in discerning among choices. Attention is focused during emotional states associated with discomfort. Perhaps emotion such as discomfort is crucial to focus attention while learning science. This idea was also suggested by Robert Karplus, the proposer of the Learning Cycle as inquiry-oriented instruction (Karplus and Thier, 1967). The next step is to evaluate whether curricula being proposed under the new AAAS and NRC guidelines actually engages students both rationally and emotionally.

The "breadth rather than depth" approach currently used in teaching science in schools rarely allows students the opportunity for experiencing this process. According to a recent study (Schmidt et al, 1996), the propensity of curricula mirrored in textbooks is to do something of everything but little of any one thing and the emphasis is in understanding and using routine procedures representing less complex and more easily taught goals. It seems as though our science curricula moved toward eliminating the frustration which might lead to a deeper understanding of a few key concepts. Knowing about the relevance of feelings in processing reasons does not imply that reason is less important than feelings or vice versa. Knowing the role that feelings play in reason should help us enhance their positive effect and reduce their potential harm. Knowing whether the discomfort associated with confusion is a normal step in the process of learning difficult science concepts should help teachers recognize the importance of helping students take advantage of motivation inherent with discomfort in order to broaden their knowledge. This view of the relationship between emotion and reason should actually empower us to recognize how to act on our feelings as we strive to control circumstances to the advantage of individuals and society by way of science and technology.

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Corporate Source: Indiana University Purdue University Indianapolis School of Education

Publication Date: January 10, 1997

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