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Epistemologies in Physics

"Knowing how to learn gives individuals the power to take control of their education and personal destinies by thinking well and processing information deeply" (Gaskins 130). This theory of knowledge and learning can be applied to all disciplines, especially physics. Most people understand that the laws of physics govern all interactions; but when they choose to or are forced to study them in class, they lose sight of the interconnectedness of the discipline. The concepts of physics not only relate to themselves but to the everyday workings of the universe. According to the Oxford American Dictionary, epistemology is the theory of knowledge, especially with regard to its methods, validity and scope. It is the investigation of what distinguishes justified belief from opinion. With regard to physics, epistemology is essentially what students believe about the content of physics, how it relates to real life and to itself and how best to learn the discipline. Over the years, research and curricular development has helped teachers and professors to improve content understanding. Unfortunately, these developments have not improved students' opinions regarding the epistemology of physics. Most students continue to see physics as a disconnected web of concepts that fits less with real world experiences than they previously thought. In order to improve physics instruction, educators must not only strive to improve content understanding but create epistemologically friendly classrooms.

Recent curricular developments in physics emphasize a more interactive approach to learning rather than traditional lectures. These methods have improved content understanding because they do not treat students as "blank slates." They take into account the idea that students begin physics class with a bag of previous conceptions (both correct and incorrect) from personal experiences about how the world works. However, because they do not address these preconceptions, it makes it difficult for students to develop conclusions that teachers desire (Redish 212). Because content understanding does directly correlate with improved epistemological outcomes, physics education must take another step in order to help students see physics and science as an interconnected web of knowledge and help them understand what science is in order to do it independently.

"Interactive Engagement (IE) methods are those designed at least in part to promote conceptual understanding through interactive engagement of students in heads-on (always) and hands-on (usually) activities which yield immediate feedback through discussion with peers and/or instructors" (Hake 2). Many colleges and high schools still follow a traditional method for teaching physics – teacher or professor led lectures. But, many colleges are moving toward a method called "Workshop Physics" in order to teach introductory physics courses. Workshop physics classes usually meet two-three times a week for two-hour sessions. Students do a reading for class and investigate the principles from the reading by conducting different lab activities and experiments in groups. Traditional lectures are rarely given and emphasis is placed on peer sharing and collaboration between students and professors. Another practice, still rare but more common to high schools, is of modeling physics. Students investigate the principles of physics from first hand experience in lab. Students do labs and investigate before being given formulas; all formulas are derived from real life experience. This method of modeling physics is one of guided inquiry. Teachers emphasize concepts over terminology and the class is centered on group lab work and peer sharing similar to that of workshop physics and how real science is done. "Experiments no longer become about following a cut and dry procedure but about wanting to know why or how something really works…Students without the ability to hypothesize miss the essence of not only physics but of science in general" (Zelaski 5). These two methods of non-traditional teaching encourage students to problematize the content by requiring students to ask questions and challenge rather than expecting them to assimilate facts, procedures and other answers (Engle 404).

As noted earlier, all students come to class with a set of attitudes, beliefs and assumptions about how physics applies to the world, what is required of them in a physics class and how they will fulfill these requirements.

> "Students who have difficulties [with physics] often view physics knowledge as a collection of facts, formulas, and problem solving methods, mostly disconnected from everyday thinking, and they view learning as primarily a matter of memorization. By contrast, successful learners tend to see physics as a coherent system of ideas, the formalism as a means for expressing and working with those ideas, and learning as a matter of reconstructing and refining one's current understanding" (Hammer 3).

Curricular developments in physics must not only emphasize an improvement in content understanding but must address the epistemologies of students in order to help better align them with those of successful physicists. The course of study must help students to mold their current productive epistemological resources from other classes to fit with physics, while helping students to build new ones. Often instructors do not list "making connections" or "modifying opinions about physics" as a goal on the syllabus. Goals such as these are frequently considered part of the "hidden curriculum." As educators, if we hope to lead students to an understanding of physics as a coherent system of ideas where equations and math are used as language and not the concept of the course, we must illuminate and address the hidden curriculum.

In order to address the hidden curriculum and improve students' epistemological beliefs, The University of Maryland has been leading the way in investigating student thoughts, opinions and the effectiveness of different curricula in modifying epistemologies. The Maryland Physics Expectation (MPEX) Survey was designed to measure student epistemologies. Students answered 34 questions by ranking their agreement with the given on a 1-5 scale. Responses were then ranked as "favorable" or "unfavorable," depending on the question, and compared to that of "experts," in this case college faculty. Students' scores were compared at the beginning and end of the semester to measure individual progress as well as class progress. Scores for the pre and post tests were also compared across schools.

The MPEX Survey contains questions related to six seemingly different but interconnected areas. The topics are Independence – beliefs about learning physics (active or passive process); Coherence – beliefs about the structure of physics (isolated pieces or linked web); Concepts – beliefs about the content of physics knowledge (concepts with formulas or formulas as concepts); Reality Link – beliefs about the connection between real life and physics (does physics relate outside the classroom); Math Link – beliefs about the role of mathematics in physics (math is just used to get an answer or math is used to represent information); Effort – beliefs about the kind of work and activities necessary to understand physics (expectations about critical thinking process and feedback). Questions on the survey included such things as

- "Learning physics is a matter of acquiring new knowledge that is specifically located in the laws, principles, and equations given in the textbook and in class and/or in the textbook" (Redish 218).

- "If I came up with two different approaches to a problem and they gave different answers, I would not worry about it; I would just choose the answer that seemed most reasonable" (Redish 218).
- "'Problem Solving' in physics basically means matching problems with facts or equations and then substituting values to get a number" (Redish 219).

MPEX was given to six different schools including the University of Maryland – College Park, The University of Minnesota, The Ohio State University, Dickinson College and two other institutions. At the beginning of the semester, the students at all colleges only agreed with expert responses 50%-60% of the time while giving unfavorable responses 15%-30% of the time. After one term of instruction, the survey showed an overall increase in unfavorable responses and a decrease in favorable responses for all institutions (Redish 218).

A significant part of the decline was seen in the Effort cluster. It is not surprising that students' responses were less favorable at the end of a semester than at the beginning; many may have thought they put in more work than they actually did. Beyond the Effort cluster, it is more unfortunate that many schools showed a decline in favorable responses related to cognitive developments. Half of the schools showed a decline in favorable responses in the Independence cluster, two-thirds in the Coherence cluster, half in the Math-Link cluster (while the other half showed no gain) and all showed a decline in the Reality-Link cluster (Redish 221). The responses to MPEX demonstrate that something about introductory physics education at the college level is not quite right. Some may argue that it is the student's fault or that physics just is not for everyone. Attitudes such as these are destructive; they bias courses in favor of students who have had previous experience with physics or higher levels of math. Furthermore, they treat physics as a zero-sum game where a student either has the ability or does not. Is it not the goal of epistemological research to eliminate binary attitudes and modify approaches to learning and development?

Einstein believed that, "The whole of science is nothing more than a refinement of everyday thinking" (1936). Physics students must be taught to see physics in this way, not as a foreign concept separate from the reality of one's own life. By addressing not only curricular but epistemological needs in the physics classroom, schools and universities can produce students who not only understand the material better and can think for themselves, but also grasp the idea of "doing science." In order for this to occur, epistemologically friendly curricula must continue to be developed, and teachers and professors must be educated in how to best display and more clearly relate the essence of physics to their students.

Creating an epistemologically friendly classroom means making the hidden curriculum explicit in order to help students to begin to reconcile their preconceptions with what is really happening in situations according to the laws of physics. "Learning physics requires identifying hidden assumptions, examining them, and trying to understand when they apply and when they do not" (Hammer 15). Shopping for ideas, as this process is known, asks students to "shop" through ideas, prior knowledge and experiences in their heads from everyday life in order to make connections to the current situation. It forces them to consider the origins of their impressions as well as locate alternative possibilities that may also apply. Since "science is nothing more than a refinement of everyday thinking," students must learn this metacognitive behavior in order to be able to identify what they are thinking in everyday situations. Once students are able to sift through their knowledge in order to illuminate their thinking process, students will be able to make sense out of their thoughts. As students, teachers and professors begin revealing their individual thought processes when applying them to a discipline such as physics, these verbalized metacognitive processes help to clarify and unite the discipline by uncovering trains of thought. Laws and equations are no longer strings of words and numbers but begin to make sense because their meaning has been analyzed and related to personal experience. As individual ideas begin to make sense, teachers and professors need to push students to unite individual ideas into a coherent system of beliefs rather than isolated facts. Just as a crossword puzzle is an isolated set of questions and answers, when put together they complete the puzzle.

As evidenced by the MPEX Survey, first year physics students often have difficulty seeing the link between reality and physics. Sometimes physics becomes so abstract that it seems these "simple" laws could no longer relate to the ordinary, or that real life is too complicated and physics cannot explain all of its intricacies. In order to create an epistemologically friendly curriculum, educators must sometimes restrict the scope of focus within the classroom. This means that students must ignore some things that do happen in the real world in order to better understand the concepts. Physicists do this in their daily work; they make simplifying assumptions in order to better understand part of the world in order to understand more of it later. In high school it might be beneficial to reduce the amount of material that is covered in a course in order to better focus on basic concepts and epistemologies. All physics curricula should include labs or other activities that can be referenced in order to help students reconcile actual experiences with physical laws. These foothold ideas give students and teachers a common reference point for discussion. New concepts can be linked with old concepts by relating laboratory experiences to classroom work and discussions. These foothold ideas can also be used as launching points for understanding implications of certain lines of thinking. If a student chooses X to be true, what must also be true? Does it fit with the foothold idea? Does X make sense or do we need to modify the foothold? Making implications further demonstrates the process of thinking in which real physicists and scientists partake. It demonstrates logical, progressive thinking and reasoning while being able to return to past ideas in order to modify or abandon them completely.

An epistemologically friendly curriculum and classroom include such elements as "shopping for ideas, sense making, coherence [seeking], restricting the scope, …foothold ideas and playing the implications game" (Redish and Hammer 4). When combined, these elements should help students to consider and reconsider their own beliefs and legitimately learn physics rather than memorize it. While in theory all classrooms should utilize these elements, the question to consider is how they may be implemented in an everyday high school or college setting.

High school is often a student's first introduction to "real" science and physics. Most people who pursue physics in high school do not study it in college. In order to better prepare those who do plan to continue studies in physics after high school and those who do not, changes to the traditional high school curriculum should be made. As previous studies have shown, non-traditional methods of teaching physics have been more successful in helping students with content understanding. These methods should be continued, but in addition, "perhaps, to best prepare students for advanced work in science… instructors of introductory physics courses should focus more on epistemological development and less on content coverage" (Elby 54). An approach such as this would slow down the instructor's current race to cover a certain amount of content in a given span of time no matter the students' understanding. This might mean covering two-thirds of the material now taught in the course in order to go more in depth and to force students to consider and modify their preconceptions. Additional time could be spent on learning and understanding the laws of physics from labs and experience rather than relying on rote memorization. Students planning to pursue physics would benefit from this type of curriculum because it would develop a more solid base upon which to build more advanced concepts. Students planning to pursue any type of science would also benefit because the same metacognitive processes can be applied to any discipline. Likewise, students not planning to pursue science will learn to consider what they are thinking, why they are thinking it and how they can apply their skills to modify or change it. A stronger foundation in scientific thinking not only benefits future science students but society in general as it teaches all students to think and analyze. Furthermore, homework should be checked for completeness and coherence rather than just right or wrong answers. Was the method employed in obtaining the answer a viable alternative and does the work progress in a logical sequence? Making learners understand that the process of scientific thinking is as critical as the solution itself should be a clearly stated goal.

Utilizing new methods for teaching physics that include better conceptual understanding and a focus on epistemology would benefit all students; however it can potentially create problems in the context of today's science teaching methods and goals. It cannot be argued that AP classes would suffer because these methods would generally be applied to introductory classes. These techniques might actually help AP Physics classes because students would enter upper level physics with a stronger foundation. Public high schools receive government funding and must meet state standards. Frequently, state standards push for physics teachers to cover so much content without regard for actual student understanding. Depending on state standards and the amount of available class time, some schools may find it difficult to implement this type of intensive, smaller scope curriculum. Furthermore, teachers need to be educated in the methods of not only physics pedagogy but in the epistemologies of physics. Teachers will need assistance designing and incorporating these new techniques into their classrooms.

Epistemologically friendly curricula should not be restricted to high school. Introductory college physics courses should also implement curricular developments that improve content understanding as well as those that improve student epistemologies. In an effort to improve content understanding, many colleges and universities are now doing “Workshop Physics” rather than the traditional lecture-lab format. If an epistemologically friendly curriculum were implemented in high schools, introductory physics classes at the college level would not be so concerned about covering “less material.” Students coming into physics would have a better background so they would be able to go through the beginning material more rapidly and cover the intended amount of coursework more easily. Assuming that not everyone has taken high school physics or that high schools do not teach epistemologically friendly curricula, colleges are left with “the problem.” Professors could assign more conceptual homework problems that require explanation rather than just numerical solutions. If a school follows a “workshop” method of education, students could be asked to journal or document their beliefs before doing the lab and then again afterward. Again, rather than doing traditional problem sets, both workshop and traditional class students should be required to turn in explanations that describe how and why the laws of physics explain a situation and how and why the result is modified or the same as the student’s preconception. A sample line of questioning may include:

1. A car cruises steadily down the highway at 60mph. Wind resistance and friction oppose the car’s motion. Those backward forces have a combined strength of 5000N. The car’s engine causes a forward force to be exerted on the car. Intuitively, is this forward force less than 5000N, equal to 5000N or greater than 5000N? Explain.
2. In this question, we’ll see if Newton’s 2^{nd} Law agrees with your intuitive guess.

a. When the car cruises at constant speed 60mph, what is its acceleration, a? Explain your answer briefly.
b. Therefore, according to $F_{net} = ma$, when the car moves at constant velocity, what net force does it feel?
c. So, is the forward force greater than, less than, or equal to the 5000N backward force? Does this agree with your intuitive answer to question 1?

3. Ok, here's the punch line. Most people have the intuition that, if an object is moving forward, there must be a (net) forward force. Explain in what sense that intuition is helpful and correct, and in what sense that intuition might seem misleading. (Hammer and Elby 32)

Assignments such as these can be explored during lab time as well as class time. Therefore, some teaching time can be saved in introductory physics by requiring the students to do epistemological work for homework or during lab.

The biggest enemy of college classes, as well as high school classes, is time. Colleges do not have the pressure of state standards but instead have a certain amount of material that needs to be covered in order to maintain their reputations and for students to succeed at the next level. A stronger foundation always builds stronger students. Colleges should not ignore epistemologies. If students really understand why and how something works and truly believe it, numerical homework problems will be easier. Another option, such as that at the University of Maryland, is to create a course titled, "How to Learn Physics" (HTLP). Other colleges and universities could follow this model and even require freshmen to take this course. In HTLP, students could go in-depth and focus more on the epistemologies of physics while still completing all of the desired coursework in their regular introductory physics courses.

Over the last 20 years, huge gains have been made in physics curricular development to improve content understanding. The epistemologies of students are too important to overlook any longer. Physics education must take another step forward and help students to refine their everyday thinking in order to align their intuitions with physics. Through this alignment process, students will not only improve their conceptual web of understanding of physics but the process will teach them to think. The ability to think and reason will afford students the opportunity to see physics as a united field related to everyday life instead of isolated concepts. Students will not, in general, develop these skills on their own. Teachers at every level must design and effectively implement epistemologically friendly classrooms.

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