Freshman Physics Majors' Cognitive Expectations and Academic Performance in their Introductory Physics Course

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The research investigates the extent of change in Physics majors' cognitive expectations – beliefs about the learning process and the structure of knowledge – after going through their first Introductory Physics course. Using the Maryland Physics Expectations (MPEX) Survey, the students' responses are compared with the responses of 'life-long learners of physics'. The students' post-instruction responses reflected highest agreement with the experts' response in the Concepts, Reality Link, and Effort Link dimensions of the survey. Analysis of the beliefs profile of the students in the upper quartile compared with the beliefs profile of the students in the lower quartile revealed that a more 'expert-like' thinking in the Coherence, Concepts, and Effort Link dimensions is present for the students who performed academically well in class.

Keywords—cognitive expectations, academic performance, Introductory Physics, beliefs about learning, MPEX

1. INTRODUCTION

The Physics Education Research Group of the University of Maryland posits that what students expect will happen in their Introductory Physics course plays a critical role in how they will respond to the course. Students' understanding of what science is about and what goes on in a science class affects what information they will listen to (and what they will ignore) given the often large amount of material their teachers flood them with (Redish et al., 1998). The study conducted by Perkins et al. (2004) further suggests that students who come into a physics course with more favorable (expert-like) beliefs are more likely to achieve higher learning gains. In order to achieve the goal of increasing student's appreciation and understanding of physics, there is a need to look at how students view physics and physics learning as these factors play a significant role in the learning process.

The current study looks at how freshman Physics majors' *cognitive expectations* – expectations about the learning process and the structure of knowledge – change after going through their first Introductory Physics course. The study also looked at the relationship between the beliefs held by the students in the different dimensions of the Maryland Physics Expectations (MPEX) Survey and the students' academic performance.

In this paper, the students' cognitive expectations were documented using the

Maryland Physics Expectations (MPEX) Survey. The MPEX is a 34-item agree-disagree survey (using a five-point Likert-scale) that probes attitudes, beliefs, and assumptions about learning physics. The survey was developed by the Department of Physics, University of Maryland. A description of the development, validation, and calibration of the instrument may be found in the paper by Redish et al. (1998).

The six dimensions of learning physics that are probed by the MPEX are: Independence, Coherence, Concepts, Reality Link, Mathematics Link, and Effort Link. The first three dimensions of the survey are taken from the research conducted by David Hammer (1994) on student's epistemological beliefs. These dimensions are:

Independence – beliefs about learning physics – the learner takes responsibility for constructing her/his own understanding or the learner takes what is given by authorities (teacher or textbook) without evaluation.

Coherence – beliefs about the structure of physics knowledge – the learner believes physics needs to be considered as a connected consistent framework or the learner believes that parts of physics can be treated as unrelated facts or pieces.

Concepts – beliefs about the content of physics knowledge – the learner attempts to understand the underlying ideas and concepts or the learner focuses on simply memorizing and using formulas.

The Maryland Physics Education Research Group (Redish et al., 1998) added the following dimensions:

Reality Link – beliefs about the connection between physics and reality – the learner believes that ideas learned in physics are relevant and useful in a wide variety of real contexts or the learner believes that ideas learned in physics has little relation to experiences outside the classroom.

Math Link – beliefs about the role of mathematics in learning physics – the learner considers mathematics as a convenient way of representing physical phenomena or the learner views physics and math as independent with little relationship between them.

Effort Link – beliefs about the kind of activities and work necessary to make sense out of physics – the learner makes the effort to use available information and make sense out of it or the learner does not attempt to use available information effectively.

The Maryland Physics Expectations (MPEX) Survey was administered to the 24 freshman Physics students at the beginning and towards the end of one trimester. These data provided the pre-instruction and the post-instruction ratings, respectively. The student's response for each item in the MPEX was compared with the "experts' response". During the development of the MPEX instrument, Redish et al. (1998) conducted consultations with lifelong learners (experienced physics instructors who have a high concern for educational issues and a high sensitivity to students) in order to develop the instrument's answer key. In presenting the MPEX data, students' responses are coded as either favorable (in agreement with the experts' response) or unfavorable (not in agreement with the experts' response).

2. DISCUSSION OF RESULTS

Table 1 shows the summary of the students' agreement / disagreement with the expert response for the six dimensions probed by the MPEX. The sum of the pre-instruction % favorable rating and the pre-instruction % unfavorable rating would not add up to 100% since some students rated a particular item with a "neutral" response.

Table 1
Percentage of students [N = 24] whose response is the same as experts (% Favorable) and whose response differs from the experts (% Unfavorable)

	% Favorable		*% Unfavorable*	
MPEX Dimension	Pre-instruction	Post-instruction	Pre-instruction	Post-instruction
Independence	29.3 %	51.0 %	46.0 %	34.2 %
Coherence	34.3 %	46.3 %	47.3 %	32.8 %
Concepts	48.2 %	68.4 %	32.6 %	14.0 %
Reality Link	54.2 %	72.6 %	19.8 %	9.8 %
Math Link	35.4 %	43.8 %	36.8 %	28.2 %
Effort Link	63.8 %	68.2 %	12.6 %	11.2 %
Over-all	44.2 %	58.4 %	32.5 %	21.7 %

In their study, Redish et al. (1998) used a Gaussian approximation to the binomial distribution to determine if a difference or shift in the average percentage response is significant. For large populations (n > = 450 students), a shift of 5% is considered significant; for smaller populations, a 10% shift may be considered significant.

2.1. Independence Dimension

This dimension looks at how students think they acquire knowledge and understanding in physics. There are students who are solely dependent on their professor and textbook as the source of information. Some students on the other hand, believe that they could search for knowledge and develop it on their own. If the students believe the latter, they are more likely to take responsibility for their own learning. The data gathered for this dimension showed a significant increase (a positive shift of 21.7%) in the favorable responses of the Physics majors.

As the learner matures, s/he takes responsibility for constructing knowledge, instead of simply relying on an authoritative source (the teacher or a textbook). For MPEX item # 13, *"My grade in this course is primarily determined by how familiar I am with the material. Insight or creativity has little to do with it."* Lifelong learners (the 'experts' in Redish et al.'s (1998) study) believe that students should disagree with this statement. At the beginning of the course, only 35% of the students exhibited the experts' response. By the end of the course, 64% of the students said that creativity and insight are needed to learn physics.

The experts say that they disagree with MPEX item # 14, *"Learning physics is a matter of acquiring knowledge that is specifically located in the laws, principles, and equations given in class and/or in the textbook."* Initially, only 2/5 of the class thought that learning physics extends beyond the textbook. By the end of the course, 60% of the class is in agreement with the experts' response.

2.2. Coherence Dimension

The Coherence dimension looks at the students' beliefs about the structure of physics knowledge and whether they see it as a collection of isolated pieces or as a single coherent system. Most often, students would see science as a collection of facts but fail to see how the facts relate with each other. Although the students who were surveyed in the study reported a 12.0% positive shift in their favorable responses when comparing the pre-instruction and the post-instruction data for this dimension, the students' view about how the concepts relate to each other could still be improved.

For example, in MPEX item # 12, *"Knowledge in physics consists of many pieces of information each of which applies primarily to a specific question."*, even at the end of the course, 90% of the students agreed with this statement which is contrary to the experts' response. The experts interviewed by Redish et al. (1998) believe that students should see physics as a coherent, consistent structure. The Physics majors who took part in the study have not yet seen the connections and relationships between the different concepts they have learned.

The students' response on MPEX item # 29, *"A significant problem in this course is being able to memorize all the information I need to know."*, reveal that up to the end of the course, one-third of the class still focus on memory work, rather than see the relationships between concepts.

2.3. Concepts Dimension

Learners who are aware of the fundamental role played by physics concepts in problem-solving view doing physics as more than the "substitute–the–givens–and–solve–mathematically" approach done in high school physics. The favorable shift in the students' response to MPEX item # 4, *"Problem solving in physics basically means matching problems with facts or equations and then substituting values to get a number."* [experts' response is disagree; students' agreement with the experts shifted from a pre-instruction value of 21% to a post-instruction value of 57%] and MPEX item # 26, *"When I solve most exams or homework problems, I explicitly think about the concepts that underlie the problem."* [experts' response is agree; students' agreement with the experts shifted from a pre-instruction value of 78% to a post-instruction value of 93%] show that the students have gone beyond the naïve view of doing physics as simply using formulas and are now moving towards understanding the ideas and concepts that support the equations.

2.4. Reality Link Dimension

Students who believe that ideas learned in physics are relevant and useful in a wide variety of real contexts will give a high rating to this dimension. The link between physics concepts and real-life experiences was seen by 72.6% of the members of the class (post-instruction favorable response). This dimension recorded the highest percentage agreement with the experts' responses showing the students' awareness of the link between ideas learned in their physics class and their experiences in the real world.

2.5. Math Link Dimension

The Math Link dimension verifies the students' beliefs about the role of mathematics in learning physics and whether they see the mathematical formalism as just a tool used to calculate numbers or as a way of representing information about physical phenomena. It is important for students to see the link between the mathematical representation and the physical phenomena in order to develop the ability to use abstract and mathematical reasoning in describing and making predictions about the behavior of real physical systems.

The Math Link dimension recorded the lowest percentage agreement with the experts' response having a post-instruction favorable response of 43.8% (from a pre-instruction favorable response of 35.4%). As observed in the Concepts dimension, the students are beginning to be aware of the value of understanding the underlying ideas and concepts, but the students still need to see the deeper physical relationships present in the equations.

2.6. Effort Link Dimension

The Effort Link dimension looks at students' beliefs about the kind of activities and work necessary to make sense out of physics and whether students expect to think carefully and evaluate what they are doing based on available material and feedback or not. A favorable response would reflect a student's willingness to make the necessary effort to make sense out of the topics in physics.

About 70% of the students in the class responded that the effort they exerted in learning physics is similar to the effort exerted by the life-long learners (experts) interviewed by Redish et al. (1998). Although there is no statistically significant change in the percentage of the students agreeing with the experts when the pre-instruction data (63.8% favorable responses) and post-instruction data (68.2% favorable responses) are compared, the results obtained in the present study differs from the result obtained by Redish et al. (1998) in their original study where they found a downward shift in the effort the students exerted. Similar to what the present study has reported, van Aalst and Key (2000) also reported a positive change in the Effort Link responses of the students enrolled in an Introductory Physics course.

2.7. Relationship Between the Different Dimensions of MPEX and Students' Academic Performance

The results of Perkins et al.'s (2004) study suggested that students who come into a Physics course with more favorable (expert-like) beliefs are more likely to achieve higher learning gains. To test this hypothesis, a comparison was made between the beliefs profile of the students in the upper quartile and the beliefs profile of the students in the lower quartile. In the context of the study, the term academic performance refers to the student's final grade in the Introductory Physics course. Students who performed academically better reported a more expert-like thinking in five MPEX dimensions: Coherence, Concepts, Reality Link, Effort Link, and Math Link. Analysis of the data in Table 2 reveals a statistically significant difference in the responses of the top 25% and the bottom 25% of the class in the Coherence, Concepts, and Effort Link dimensions of MPEX. Students who focused on understanding the underlying ideas and concepts and those who saw the unity and connectedness of the various Physics concepts obtained a higher final grade in the Introductory Physics course.

Table 2
Comparison of percentage agreement with experts' response between the two groups of students

MPEX Dimension	*% favorable response of students in the upper quartile*	*% favorable response of students in the lower quartile*
Independence	40.0 %	40.0%
*Coherence **	46.7 %	22.9 %
*Concepts **	56.1 %	36.2 %
Reality Link	70.0 %	62.9 %
Math Link	50.0 %	42.9 %
*Effort Link **	71.4 %	60.0 %

* statistically significant difference at 95% level of confidence

Table 3 demonstrates that students who responded with "expert-like" views in the Math Link dimension also gave "expert-like" responses in the Independence (r = 0.853), Coherence (r = 0.727), Concepts (r = 0.727), and Reality Link dimensions (r = 0.677).

Table 3
Correlation coefficients when comparing the MPEX Dimensions with Each Other and with Students' academic performance / final grade in the course

	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
Independence (1)	1.000						
Coherence (2)	0.476	1.000					
Concepts (3)	0.871	0.422	1.000				
Reality Link (4)	0.476	0.630	0.382	1.000			
Math Link (5)	0.853	0.727	0.727	0.677	1.000		
Effort Link (6)	0.045	0.280	0.083	0.134	0.081	1.000	
Academic Performance (7)	0.135	0.576	0.113	0.128	0.107	0.094	1.000

The high correlation (r = 0.871) between the Independence and Concepts dimensions leads us to posit that students who approach physics with a perspective of discovering the information by themselves (and not simply relying on an authority figure) are able to learn the physics concepts better. Students who see physics as a unified, coherent structure also tended to see the relevance of physics in daily life. This may be gleaned from the 0.630 correlation rating between the Coherence dimension and the Reality Link dimension.

Looking at the correlation values between the student's academic performance (measured by their final grade in the course) and the MPEX dimensions of learning, what stands out in Table 3 is the 0.576 correlation rating between the Coherence dimension and the students' academic performance. This relationship is something that could be explored further in future studies.

3. SYNTHESIS

The students' responses reflected highest agreement with "experts" in the Concepts, Reality Link, and Effort Link dimensions of the Maryland Physics Expectations (MPEX) survey. The Physics majors are putting in the effort needed to understand physics. Analysis of the beliefs profile of the students in the upper quartile and the beliefs profile of the students in the lowest quartile revealed a significant difference in the beliefs profile of the two groups. Students who obtained higher grades reported a more expert-like thinking in the following MPEX dimensions: Coherence, Concepts, and Effort Link. Finally, the study has shown that an expert-like belief in the Coherence dimension correlates moderately with good academic performance.

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