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How Do Education Students Learn Physics?

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Research in physics education has identified students' attitudes and beliefs that contribute to higher gains in learning. The study investigated the extent of change in education majors' attitudes, beliefs and cognitive expectations after going through an introductory physics course. Using the MPEX (Maryland Physics Expectations) Survey and the CLASS (Colorado Learning Attitudes about Science Survey), the students' responses were compared with the responses of "life-long learners of physics". In the MPEX, the students' post-instruction responses reflected high agreement with the experts' responses in the concepts, effort link, reality link and math link dimensions of the survey. The students posted high agreement with experts' beliefs in the CLASS categories relating to personal interest, real-world connections, sense-making/effort and problem-solving (confidence). The relationships among the attitudes, beliefs and cognitive expectations they held and their academic performances were also presented. The results of the correlation analysis revealed that providing opportunities for students to make sense of the information given to them leads to a deeper appreciation and interest in the subject matters and allows them to connect their real-world experiences with concepts and ideas learned in their physics class. Meaningful learning in a physics class is achieved when students have a firm grasp of the basic concepts in the discipline, allowing them to make sense of the information given to them, thus, leading them to exert the effort required of them. This eventually empowers them to create connections and relationships among the ideas they learned.

Keywords: attitudes, beliefs, education students, introductory physics, learning

Introduction

It is important to know what beliefs and attitudes bring about meaningful learning in our classrooms. Research in science education has identified that students' attitudes and beliefs shape their classroom experience (Bransford, Brown, & Cocking, 2002; Elby, 2001; Redish, 2003). Perkins, Adams, Pollock, Finkelstein, and Wieman (2004) examined the relationship between students' beliefs about physics and other educational outcomes, such as conceptual learning and retention, and identified a positive correlation between students' attitudes and beliefs, measured using the CLASS (Colorado Learning Attitudes about Science Survey), and normalized conceptual learning gains measured by using two standardized conceptual inventory tests, the "Force Concepts Inventory" (Hestenes, Wells, & Swackhamer, 1992) and the "Force and Motion Conceptual Exam" (Hestenes & Wells, 1992). Their analysis suggested that college-level students who come into a physics course with more favorable or expert-like beliefs are more likely to achieve higher learning gains.

During academic year of 2006-2007, De La Salle University, a private higher educational institution in Manila, Philippines, began implementing the Lasallian (general education) Core Curriculum. The new

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curriculum consists of a set of foundational, formative and integrative courses that aim to develop in students a critical appreciation of the diverse fields of human knowledge, their principles and science and their arts and methods of inquiry (Rapatan, Zamora, Malabanan, Limjap, Razon, & Mistades, 2005). The Lasallian (general education) Core Curriculum is rooted in a transformative learning framework—a process of acquiring knowledge by synthesizing what is known with something that is not known through questioning assumptions, beliefs and values and considering multiple points of view, while always seeking to verify truth and reason. This process aims to transform a student's beliefs, attitudes and emotional reactions by providing opportunities for the student to critically reflect on his/her learning experiences.

The Lasallian (general education) Core Curriculum aims to expand students' critical and creative thinking skills by engaging them in various modes of inquiry. In the new curriculum, students are envisioned to develop knowledge as a result of their inquiries, actions and experimentations. Included in the core curriculum is a three-unit course on physics offered to students as one of their natural sciences courses. SCIENVP (Introductory Physics-Energy and the Environment track) focuses on the relationship between energy and the environment. It covers the study of the various sources of energy, the effects of using each energy source on man and his environment and the pollution associated with energy consumption. The course aims to develop among students an awareness of their roles to help protect and conserve the environment through the wise use of energy resources.

The physics education research group of the University of Maryland (Redish, Saul, & Steinberg, 1998) posited that what students expect to 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 materials their teachers flood them with. The study conducted by Perkins et al. (2004) further suggested that students who come into a physics course with more favorable 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 objective of the current study was to present a profile of the attitudes, beliefs and cognitive expectations of 37 freshman education students (with specialization in early childhood education) towards their Introductory Physics-Energy and the Environment course. These attitudes and beliefs will then be correlated with their academic performance. The data that will be generated will be the basis for identifying what specific beliefs and attitudes are factors that influence meaningful learning in physics. The insights that will be drawn from the current study will be a valuable contribution to the growing body of physics education research.

Methodology

In this paper, students' cognitive expectations were documented using the MPEX (Maryland Physics Expectations) Survey. The MPEX is a 34-item agrees-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 freshman education students in the Introductory Physics (Energy and the Environment) class took the MPEX survey at the beginning of the term to generate the pre-instruction data and again at the end of the term to generate the post-instruction data. The students' responses 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. When a student's response to the survey item is in agreement with the response of the expert group, the response is described as favorable; otherwise, it is described as unfavorable.

The six dimensions of learning physics that were probed by the MPEX are: independence, coherence, concepts, reality link, mathematics link and effort link. The first three dimensions of the survey were taken from David Hammer's (1994) research on student's epistemological beliefs. These dimensions are:

(1) 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 and textbook) without evaluation;

(2) Coherence—beliefs about the structure of physics knowledge, the learner believes that 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;

(3) Concepts—beliefs about the content of physics knowledge, the learner attempts to understand the underlying ideas and concepts or the learner focuses on memorizing and using formulas.

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

(1) 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 have little relation to experiences outside the classroom;

(2) 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;

(3) 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 CLASS (Adams, Perkins, Podolefsky, Dubson, Finkelstein, & Wieman, 2006) is built on work done by existing surveys. The survey probed students' beliefs about physics and learning physics, and distinguishes the beliefs of experts from those of novices. Participants taking the CLASS inventory were asked to respond on a five-point Likert ("Agree"—"Disagree") scale to 42 statements, such as:

> "Learning physics changes my ideas of how the world works" (Item 28).
>
> "If I get stuck on a physics problem on my first try, I usually try to figure out a different way that works" (Item 15).
>
> "Reasoning skills used to understand physics can be helpful to me in my everyday life" (Item 30).

Scoring of the CLASS is calculated by determining the percentage of responses for which a respondent agrees with the experts' views (tagged as "percent favorable"). The average "percent unfavorable" is also determined by taking the number of responses for which the respondent disagrees with the experts' views. The survey is scored "overall" and for eight categories: (1) real-world connection; (2) personal interest; (3) sense-making/effort; (4) conceptual connections; (5) applied conceptual understanding; (6) problem-solving (general); (7) problem-solving (confidence); and (8) problem-solving (sophistication). Each category consists of four to eight statements that characterize a specific aspect of thinking. Together, these categories include 27 of the 42 statements. The overall score includes these 27 statements, plus additional nine statements, all 36 of which passed the validity and reliability tests conducted by the University of Colorado Physics Education Research Group (Adams et al., 2004). In the current version of the survey (version 3, available through http://CLASS.colorado.edu), six statements do not yet have an "expert" response and are not included in the analysis.

Results and Discussion

The MPEX Survey

Table 1 shows the summary of the education students' agreements/disagreements with the experts' responses for the six dimensions probed by the MPEX.

Table 1

Education Students' Responses in the Dimensions of the MPEX Survey

Dimension	Favorable (%)		Unfavorable (%)	
	Pre-instruction	Post-instruction	Pre-instruction	Post-instruction
Independence	31.4	34.0	44.9	44.9
Coherence	27.0	36.2	45.4	41.5
Concepts	40.0	43.9	34.6	34.6
Reality link	65.4	66.4	23.1	19.2
Math link	53.9	55.4	26.9	26.2
Effort link	73.1	77.7	9.2	8.5
Over-all	49.1	51.7	30.0	29.0

Independence Dimension

As the learner matures, he/she 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", life-long learners (the experts in Redish et al.'s (1998) study) believed that students should disagree with this statement. At the beginning of the course, only 15% of the students exhibited the experts' responses. By the end of the course, 61% of the students said that creativity and insight are needed to learn physics.

The results obtained by the current study (34% favorable responses) for the independence dimension were similar to those obtained by van Aalst and Key (2000) for the liberal arts students (n = 102) they surveyed (32% favorable pre-course responses to 33% favorable post-course responses) and for the life sciences majors (n = 147) they surveyed (32% favorable pre-course responses to 35% favorable post-course responses).

Coherence Dimension

The experts interviewed by Redish et al. (1998) felt strongly that students should see physics as a coherent and consistent structure. Students who approach science as simply a collection of facts fail to see the integrity and coherence of the whole structure. For MPEX item 12, "Knowledge in Physics consists of many pieces of information each of which applies primarily to a specific question", 85% of the students agreed with this statement which is contrary to the experts' response. The students have not yet seen the connections among the different concepts they have learned.

The students' responses on MPEX item 29, "A significant problem in this course is being able to memorize all the information I need to know", revealed that up to the end of the course, about one-third of the class (30.8%) still focused on memory work, rather than see the relationships among concepts.

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' responses 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' responses are disagree; students' agreement with the experts shifted from a pre-instruction value of 7.7% to a post-instruction value of 46.2%) and MPEX item 26, "When I solve most exams or homework problems, I explicitly think about the concepts that underlie the problem" (experts' responses are agree; students' agreement with the experts shifted from a pre-instruction value of 73.1% to a post-instruction value of 80.8%) showed that the students have gone beyond the naive view of doing physics as simply using formulas and are now moving towards understanding the ideas and concepts that support the equations.

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 66.4% of the members of the class. This dimension recorded the second highest percentage agreement with the experts' responses which may be attributed to the use of real-life examples throughout the course. The results obtained in this dimension for the current study were much better than the results reported by van Aalst and Key (2000) where they noted that at the end of one semester, the percentage agreement with experts is 37% for both groups they surveyed.

Math Link Dimension

The math link dimension recorded a 55.4% favorable agreement with the experts' responses. As seen in the concepts dimension, the students were beginning to be aware of the value of understanding the underlying ideas and concepts and see the meaning of the physical quantities presented in the equations. The results reported for the current study are better than that reported by van Aalst and Key (2000) where they noted that at the end of one semester, the percentage agreement with experts is pegged at 35% for the liberal arts students and 34% for the life sciences majors.

Effort Link Dimension

About three fourths of the total number of students in the class have responded that the effort they exert in learning physics is similar to that 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 (73.1% favorable responses) and post-instruction data (77.7% favorable responses) were compared, the results obtained in the present study differs from the result obtained by Redish et al. (1998) who 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.

The CLASS

Table 2 presents the summary of the favorable and unfavorable responses given by the education students for each of the categories of the CLASS. The post-instruction profile of the students surveyed revealed that the respondents gave 58.2% favorable (over-all) responses (agreement with the experts) and 19.5% unfavorable (over-all) responses. The remaining 22.3% of the responses were rated as neutral (neither in agreement with nor in disagreement with the experts' responses).

Table 2

Education Students' Responses in the CLASS

Category	Favorable response (in agreement with experts)		Unfavorable response (in disagreement with experts)	
	Pre-instruction (%)	Post-instruction (%)	Pre-instruction (%)	Post-instruction (%)
Personal interest	57.1	73.7	10.9	2.6
Real-world connection	68.3	74.0	11.5	7.7
Problem-solving (general)	61.5	69.7	13.9	6.3
Problem-solving (confidence)	56.7	64.4	17.3	11.5
Problem-solving (sophistication)	32.3	46.2	32.3	18.6
Sense-making/effort	64.8	72.5	10.4	7.1
Conceptual connections	53.5	57.1	26.5	19.2
Applied conceptual understanding	34.8	37.4	43.6	37.4
Over-all	54.6	58.2	22.4	19.5

This over-all favorable response profile is slightly higher than the over-all favorable response profile for non-science majors taking up their first college physics course as reported by the developers of the CLASS instrument. Adams et al. (2004) reported that during academic year of 2003-2004, the 76 non-science students from an American state research university who were surveyed posted a 57% favorable (over-all) profile.

Personal Interest Category

This category probes whether the respondents exhibit a personal interest in or a "connection" to the study of physics. When asked if they "think about the physics (they) experience in everyday life" (CLASS item 3), only 12% gave an unfavorable response. This may lead us to hypothesize that the students see the role of physics in their personal life. Furthermore, we saw in the students' responses to CLASS item 14, "I study physics to learn knowledge that will be useful in my life outside of school" (81% favorable responses) and CLASS item 30, "Reasoning skills used to understand physics can be helpful to me in my everyday life" (85% favorable responses), there is an appreciation of the skills learned in a physics class and these skills are found to be helpful to the students' lives outside of school.

Real-World Connections Category

In the real-world connections category, the students were asked whether they think about their personal experiences and relate them to the topic being analyzed (CLASS item 37). Majority of the students responded favorably to this item. This positive outlook, combined with the 81% favorable response for CLASS item 28, "Learning physics changes my ideas about how the world works", revealed that the students believe that the ideas learned in a physics class are relevant and useful in a wide variety of real-world contexts.

Problem-Solving Cluster

The problem-solving cluster looks at three inter-related categories. The respondents were asked to state whether they enjoy solving physics problems (CLASS item 25) and whether they can usually figure out a way to solve physics problems (CLASS item 34). The students surveyed in the present study reported a commendable favorable response profile (agreement with experts) in two of the three categories that dealt with attitudes and beliefs about problem-solving in physics—problem-solving (general) 69.7% favorable profile and a 64.4% favorable profile for the problem-solving (confidence) category. However, the students' levels of sophistication when approaching problem-solving in physics is an area can be improved further. Sixty-five percent of the students reported that if they want to apply a method used for solving one physics problem to another problem, the problems must involve very similar situations (CLASS item 22).

There are two statements that are found in the three inter-related problem-solving categories and for both statements, the students surveyed in the study reported a respectable favorable response. Sixty-four percent of the respondents reported that they can usually figure out a way to solve physics problems (CLASS item 34). Majority of the respondents (58%) reported that if they get stuck on a physics problem, there is still a chance they will figure it out (CLASS item 40), which is similar to the experts' views.

The average rating for the problem-solving cluster—problem-solving (general), 69.7% favorable response; problem-solving (confidence), 64.4% favorable response; and problem-solving (sophistication), 46.2% favorable response reported for this study follows the same trend noted by the Physics Education Research Group at the University of Colorado (Adams et al., 2006) for their students (n = 397) taking up a calculus-based physics 1 course: problem-solving (general), 58% favorable response; problem-solving (confidence), 58% favorable response; and problem-solving (sophistication), 46% favorable response.

Sense-Making/Effort Category

This category probes whether the learner makes the effort to use available information and make sense out of the information in learning physics. The Physics Education Research Group at the University of Colorado (Adams et al., 2006) reported 73% favorable responses for students who took a reform-oriented physics course. In the present study, the education students who were surveyed posted an average of 72.5% favorable responses (agreement with experts) for the seven questions included in the category. The respondents reported that "It is important (for them) to make sense out of formulas before they can be used correctly" (CLASS item 24, 88% favorable responses). Further, they articulated that they "explicitly think about which Physics ideas apply to a problem" (CLASS item 39, 77% favorable responses).

Conceptual Connections and Applied Conceptual Understanding Cluster

Life-long learners of physics strongly feel that students should conceptualize physics as a coherent and consistent structure (Redish et al., 1998). Students who emphasized science simply as a collection of facts failed to conceptualize the integrity and coherence of the whole structure of physics. The two categories discussed in this section probed how deeply the students conceptualized physics as being coherent and how the students drew out connections among the different ideas learned.

The conceptual connections' profile of the education students surveyed show a 57.1% agreement with experts, while the applied conceptual understanding profile revealed a 37.4% agreement with the experts' responses. Although 73% of the respondents gave an expert-like response to CLASS item 42, "When studying Physics, I relate the important information to what I already know, rather than just memorizing it the way it is presented", there seems to be a disconnect with how the students view their learning process because 65% of the respondents reported that "A significant problem in learning Physics is being able to memorize all the information I need to know" (CLASS item 1).

The results in these two related categories lead us to say that the students still need to gain a deeper understanding of how the various concepts and ideas in the course are related to each other.

Relationship Between the Different Categories of CLASS and Students' Academic Performance

The study also investigated the relationship among the beliefs held by students in the different categories of the CLASS. As expected, the responses in the problem-solving clusters—problem-solving (general), problem-solving (confidence) and problem-solving (sophistication) were highly and significantly correlated with each other, as indicated in Table 3 (the *r*-values ranges from 0.527 to 0.883). The respondents gave a consistent response that supports their agreement (or disagreement) with the experts' responses in the "conceptual connections" and "Applied conceptual understanding" categories, as these two categories were highly and significantly correlated with each other (r = 0.813).

Table 3

Correlation Coefficients When Comparing the CLASS Categories With Each Other and With Students' Academic Performances

	Personal interest	Real-world connection	Problem-solving (general)	Problem-solving (confidence)	Problem-solving (sophistication)	Sense-making/ effort	Conceptual connections	Applied conceptual understanding	Over-all
Personal interest	1.0000								
Real-world connection	0.7309	1.0000							
Problem-solving (general)	0.3787	0.5044	1.0000						
Problem-solving (confidence)	0.1719	0.3145	0.8833	1.0000					
Problem-solving (sophistication)	0.0131	0.0731	0.3874	0.5270	1.0000				
Sense-making/ effort	0.5359	0.5519	0.3260	0.1727	0.0858	1.0000			
Conceptual connections	0.1828	0.0589	0.1521	0.0418	0.3217	0.2008	1.0000		
Applied conceptual understanding	0.2491	0.0825	0.0950	0.1462	0.6897	0.0139	0.8131	1.0000	
Over-all	0.5730	0.6844	0.7352	0.6094	0.3240	0.7613	0.4277	0.3169	1.0000
Academic performance	0.0747	0.0712	0.3706	0.2601	0.1725	0.1390	0.1970	0.4234	0.0955

It is noteworthy to point out that the applied conceptual understanding profile and the problem-solving (sophistication) profile were highly and significantly correlated with each other (r = 0.689). This leads us to posit that a student's level of confidence and sophistication when approaching problem-solving in physics is dependent on the level of coherence and understanding of the various physics concepts.

The correlation among the personal interest category and the following categories: real-world connection (r = 0.731), problem-solving (general) (r = 0.379), applied conceptual understanding (r = 0.250) and sense-making/effort (r = 0.536), revealed that a student's interest in physics is facilitated by these clusters.

When students actively make sense of the information given to them and exert the effort needed to understand physics ideas and concepts, they are able to approach word problems in a constructive manner, as reflected in the correlation between the sense-making/effort profile and the problem-solving (general) profile (r = 0.326). A student's sense-making/effort profile is mediated by his/her interest in the subject (r = 0.536) and his/her ability to connect real-world experiences with the ideas learned in the physics class (r = 0.552).

Table 3 also shows that expert-like beliefs in the applied conceptual understanding category and the problem-solving cluster correlate highly with good academic performance (*r* = 0.423 and 0.371, respectively).

Relationship Between the Different Dimensions of MPEX and Students' Academic Performances

Table 4 demonstrates that students who responded with expert-like views in the math link dimension also gave expert-like responses in the independence (*r* = 0.751), coherence (*r* = 0.512), concepts (*r* = 0.386) and reality link dimensions (*r* = 0.360).

The correlation between the independence and concepts dimensions (*r* = 0.523) leads us to posit that students who approach physics with a perspective of discovering the information by themselves (but not simply relying on an authority figure) are able to learn the physics concepts better. Students who see physics as a unified and coherent structure also tended to see the relevance of physics in daily life. This may be gleaned from the correlation rating of 0.538 between the coherence dimension and the reality link dimension.

Table 4

Correlation Coefficients When Comparing the MPEX Dimensions With Each Other and With Students' Academic Performances

	Independence	Coherence	Concepts	Reality link	Math link	Effort link	Over-all
Independence	1.0000						
Coherence	0.4927	1.0000					
Concepts	0.5230	0.5324	1.0000				
Reality link	0.3198	0.5380	0.1249	1.0000			
Math link	0.7507	0.5120	0.3855	0.3598	1.0000		
Effort link	0.0043	0.2258	0.0211	0.3826	0.0743	1.0000	
Over-all	0.7207	0.8364	0.5324	0.7086	0.6668	0.3782	1.0000
Academic performance	0.1649	0.0570	0.3864	0.0392	0.1492	0.2024	0.0709

Table 4 also shows that an expert-like belief in the concepts dimension leads to better academic performance as reflected in the correlation rating of 0.386 between the MPEX concepts dimension and the students' academic performances.

Synthesis

The education students taking up their Introductory Physics-Energy and the Environment course reported agreement with experts' beliefs in the following categories of the CLASS: sense-making/effort, (73%); problem-solving (confidence, 64%); real-world connections (74%); problem-solving (general, 70%); and personal interest (74%). Their responses reflected highest agreement with experts in the concepts (44%), math link (55%), reality link (66%) and effort link (78%) dimensions of the MPEX survey. The students' experiences in the physics course allowed them to appreciate the skills they gained through the various learning activities in the course and the effort they have exerted in learning the concepts involved. The students affirmed that the ideas learned in the classroom are relevant and useful in a wide variety of real-world contexts. The students likewise realized that the skills they gained in the course will be useful to their life outside of school. The study has also shown that an expert-like belief in the concepts dimension of MPEX and the applied conceptual understanding category of CLASS correlate highly with good academic performance.

The data gathered for the three other categories of the CLASS revealed that the students' beliefs in the problem-solving (sophistication), conceptual connections and applied conceptual understanding categories, with favorable responses of 46%, 57% and 37%, respectively, can still be improved. The MPEX data on coherence dimension (36% favorable responses) support these findings. These results tell us that physics educators would have to work on these areas of the students' learning experience. The challenge to educators is how to lead the students to see the connections and relationships among the various ideas presented to them. Cognitive tools, like concept maps (Novak, 1990; Mistades, 2009), have been found to be useful in this area of the teaching-learning process.

The results of the correlation analysis revealed that providing opportunities for students to make sense of the information given to them leads to a deeper appreciation and interest in the subject matter and allows them to connect their real-world experiences with concepts and ideas learned in their physics class. Meaningful learning in a physics class is achieved when students have a firm grasp of the basic concepts in the discipline, allowing them to make sense of the information given to them, thus, leading them to exert the effort required of them. This eventually empowers them to create connections and relationships among the ideas they learned.

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