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ABSTRACT

This study examines the changes in students' conceptual thinking and problem solving abilities. Conceptual thinking skills and problem solving abilities are important factors for medical school applicants as diagnosis and treatment procedures strongly depend on these skills. Underrepresented minorities in medicine is a concern in United States, and low numbers of minority students in the medical field may indicate that disadvantaged students are not successfully mastering these skills. Post baccalaureate programs may be one way of assisting these students in overcoming their deficits and make them competitive medical school applicants. The study was conducted for eight weeks among voluntary educationally disadvantaged post baccalaureate students. (Contains 35 references.) (YDS)

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by

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INTRODUCTION

The purpose of this study is to examine the extent to which studentsí problem solving abilities and conceptual thinking change as a result of enrollment in a constructivist college-level physics course. Grades were not the only thing at stake for students enrolled in the course. Students involved in the study were enrolled in the physics course because of their participation in a postbaccalaureate (postbacc) program designed to better prepare them for the medical school application process. In addition to imparting the expected introductory level content knowledge in physics, studentsí involvement in the physics course was designed to equip them with problem solving and conceptual thinking skills that are applicable to a variety of academic contexts. Evidence of studentsí ability to transfer the problem solving skills they learned in the physics class to non-physics settings was most clearly seen in their use of the problem solving skills from the course on the Medical Colleges Admissions Test (MCAT). Refined problem solving skills and highly developed conceptual thinking skills are not only transferable to other settings, they are life long learning skills that serve students well, beyond the walls of a physics classroom.

Successful problem solving and conceptual thinking skills are also important factors in determining which students become successful medical school applicants and students. Attaining these skills is especially crucial for medical students and becomes an important factor related to studentsí success on the MCAT (Association of American Medical Colleges, 1995). The diagnosis and treatment of patients relies heavily on strong problem solving and critical thinking skills. Low numbers of minority students in medical school may indicate that disadvantaged students are not successfully mastering these skills. The concerns surrounding low enrollment of minority students in medical school are substantial. The disparity between the proportion of minorities practicing medicine and the overall minority population in the United States is an issue of growing concern as is the need to alleviate the shortage of physicians in medically underserved areas (Tekian, 1997). The Association of American Medical Colleges (AAMC) designates four ethnic groups as underrepresented minorities: Blacks, Mexican Americans, mainland Puerto Ricans and American Indians (Nickens, Ready, & Petersdorf, 1994). These groups make up 21% of the population of the United States (Association of American Medical Colleges, 1996) but only 8.6% of the physician population (Libby, Zhou, & Kindig, 1997) and about 13% of entering medical school classes (Rivo & Kindig, 1996).

Postbaccalaureate Programs

One of the ways that students are assisted in their quests to become physicians is with post-baccalaureate programs. Post-baccalaureate programs take a variety of forms and target a wide range of student problems, but the basic goal of all such programs is to help students overcome deficits in their backgrounds so that they are competitive medical

school applicants. The university at which this study took place has a post-baccalaureate program for educationally disadvantaged students that show a commitment to return to shortage area care. This program targets students with a grade point average between 2.5 and 3.2 and scores on the Medical Colleges Admission Test between four and six on each of the numerically scored sub-tests. The numerical criteria and requirements for showing educational disadvantage and interest in shortage area care have resulted in classes that have primarily been composed of minority students, although race is not a criterion for selection.

One unique characteristic of the postbacc students is their ability to reflect upon their learning experiences and draw meaningful conclusions about the extent to which they have changed as learners. The postbacc students are familiar with experiencing a lack of success and not meeting their potential as learners, as evidenced by their unsuccessful attempts to gain admission to medical school. This familiarity with not succeeding has been a learning experience for these students. Rather than giving up on their pursuit to

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become medical students, the postbaccs take an alternate approach to their learning process: they become reflective thinkers and think deeply about how they can become effective learners. Experience with a type of learning that does not work for them gives postbacc students an acute awareness of what facilitates their learning most effectively. As a result, the postbacc students are an excellent source of information about their own learning.

The postbacc program takes place over the course of three quarters, beginning with a nine week summer session, followed by fall and winter quarters. During the nine-week summer session, students are enrolled in the six-week physics course, Physics A. Their time is also spent reviewing content for the MCAT and studying test-taking skills for the exam. During fall and winter quarters, students are enrolled in upper division science course work while also refining their interviewing skills in anticipation of medical school interviews.

Seventy-five of the 91 students participating in the program since 1991 have been accepted into allopathic medical schools (59 students), osteopathic medical schools (nine students), masterís of public health programs (four students), physicianís assistant programs (two students) or international medical school (one student), an overall placement rate of 82.4% (Broussard, personal communication, 1998). This is comparable to other programs that have been reported: 83.2% for the Health Careers Opportunity Program undergraduate enrichment program reported by Lewis (1996), 63% for the Minority Medical Education Program described by Cantor, Bergeisen and Baker (1998), and 53.3% for the postbaccalaureate program described by Van Winkle and Perhac (1996). A particular area of emphasis in many of these program is the identification of potentially successful medical school candidates who do not have academic credentials that meet traditional criteria. Underrepresented minority applicants often have dramatically lower grade point averages and Medical Colleges Admission Test scores than do non-minority students (Association of American Medical Colleges, 1996; Koenig & Leger, 1997; Vancouver, Reinhart, Solomon, & Haf, 1990), and it is critical to explore the factors outside of these scores that contribute to studentsí success in medical school.

At the other end of the spectrum from studies on the results of individual

postbaccalaureate programs are articles dealing with schoolsí experience with postbaccalaureate students from a variety of programs. Hojat, Blacklow, Robeson, Veloski and Borenstein (1990) found that students without postbaccalaureate experience were younger and had higher undergraduate grade point averages than those students who had participated in postbaccalaureate programs, and these students received higher grades on some measures of performance in medical school. However, when adjustments were made for undergraduate grade-point averages using analysis of covariance the advantage of the non-postbaccalaureate students disappeared. Smith (1991) reports similar results, although this study did not find any statistically significant differences between the performances of students with and without postbaccalaureate experiences. The notable results from this study were that the students with postbaccalaureate experience had much more diverse backgrounds than students entering medical school immediately after graduating from an undergraduate institution. Examples of interesting backgrounds include students who had extensive volunteer experience with the homeless, were professional musicians, were teachers, had studied philosophy in Germany or art in Egypt. This diversity of backgrounds was considered important because of the balance it gave to the student body in the medical school. Smith makes clear his stance as a proponent of postbaccalaureate programs.

Undergraduate Education in Physics

Supporting students through placing them in academic settings that foster the development of critical thinking and problem solving skills is one method of preparing them to become strong medical school applicants and students. Course work is one academic setting in which students may be able to get the support they need. The physics department at the university where this postbacc program takes place offers an introductory physics series, referred to herein as Physics A, that focuses on these essential skills. The development of the series of three courses stemmed from a genuine concern within the physics education community: too few undergraduate students are benefiting from the traditional introductory physics course which typically splits students

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time almost evenly between lecture and laboratory and relies heavily on lecture to convey new material.

Researchers have documented that traditional introductory physics courses leave students confused about basic mechanics (Viennot, 1979; McDermott, 1980; Trowbridge, 1981; Caramaza, McCloskey, & Green, 1981) as well as electricity and magnetism, optics, heat and thermodynamics and other basic physics topics (Lawson & McDermott, 1987; Goldberg & McDermott, 1986; Arons, 1997; Halloun & Hestenes, 1985). For example, Trowbridge and McDermott (1980) completed 300 demonstration interviews in order to assess college undergraduates who were enrolled in a variety of introductory science courses, including physics. As part of the interview, each student observed two steel balls rolling down two different tracks, one of which had a steeper incline. One of the more telling outcomes was how the physics students based speed comparisons on ball position and not velocity.

> Although students who were unsuccessful could generally give an acceptable definition for velocity, they did not understand the concept well enough to be able to determine a procedure they could use in a real physical situation for deciding if and when two objects have the same speed. Instead they fell back on the perceptually obvious phenomenon of passing. Some identified ahead or being behind as being faster or slower. (Trowbridge & McDermott, 1980, p. 1027)

These deficiencies have caused researchers such as Hestenes (1987) to call for exploration into new methods to teach introductory physics:

> Cognitive research in the last decade has documented serious deficiencies in traditional physics instruction. There is reason to doubt that these deficiencies can be eliminated without extensive pedagogical research and development. . . . The fact that, with sufficient time and effort, some students learn physics in our universities should not make us complacent. The question is not whether students can learn physics, but whether instruction can be designed to help them learn it more efficiently. (p. 440)

Researchers have begun to explore methods for improving introductory physics courses (McDermott, 1991; McDermott, 1993; Samiullah, 1995; Hestenes, 1987; Hestenes, 1996). Some of these methods include encouraging students to make and use scientific models, utilize scientific reasoning skills, engage in student to student interactions and relate concepts to one another and the real world. The design of implementation of this novel series of physics course work, stemmed from this universityís attempt to improve introductory physics courses.

METHODOLOGY

Sample Population

This study was conducted over the course of eight weeks and involved an introductory physics course held during the first summer session at a large Western research university. One week before and after the course were used for interviewing. The six-week course, developed by the physics department, is based on constructivist principles that focus on developing the ability to solve problems, think critically and integrate concepts. The participants in the study were seventeen students enrolled in a postbaccalaureate program sponsored by the universityís medical school. This postbaccalaureate program targets educationally disadvantaged students that demonstrate a commitment to return to shortage area care. Postbacc students in the program have a grade point average that falls between 2.5 and 3.2. MCAT scores for these students are between four and six on each of the numerically scored sub-tests. Participation in the study was voluntary, and all members of the 1998-99 class of postbaccalaureate students were involved in the investigation. Ten female and seven male students from the following ethnic groups participated in the study: seven Latino/a students, five African American students, two Filipino students, one Native American student, one Asian student, and one Caucasian student.

Materials

The measuring instruments used in the study were designed by the researchers and included three face-to-face interviews and one written questionnaire. The first interview protocol asked respondents to

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identify their perceived academic strengths and weaknesses in the sciences and assessed their understanding of some common physics misconceptions. The second interview protocol was comprised of five open-ended questions designed to examine several dimensions of studentsí experience in the physics course, including their perceptions of skills they are gaining in the course, the group work component of the course and their motivation level. Two additional questions included in the second interview were physics misconception questions used in the first interview. These questions were included to assess student gains in knowledge and possible changes in thinking surrounding core physics concepts. The items in the third interview were five Likert scale statements and eight open-ended questions. The third interview ascertained student perceptions of the extent to which the physics course had influenced their performance on the physical sciences portion of the MCAT and the extent to which skills they gained in the course are applicable to other areas. Students were also asked to reflect on the role of the teaching assistant and the extent to which he affected their learning. One physics misconception question included in the third interview protocol was identical in concept to one misconception question used in the first and second interviews. The written questionnaire, distributed to students at the end of their second week in the course, contained six Likert style statements and six open-ended questions designed to survey studentsí level of satisfaction and academic experience in the physics course. Scores students received on the MCAT prior to entering the postbacc program were compared with their scores from the August 1998 exam, in order to track improvements in their scores.

Data Collection

Data was collected to document the experience of the postbaccalaureate students in Physics A, to assess changes in students' ability to solve problems, and to examine whether they felt they were able to apply newly gained problem solving skills to the MCAT. A combination of data collection methods was used over the course of the eight-week study. Qualitative data was collected from individual student interviews, a written survey and participant observations conducted during the laboratory component of the physics course. The first interview with all seventeen students took place one week prior to the start of the course, which also coincided with the studentsí first week in the postbaccalaureate program. Fourteen students completed the written survey at the end of their second week in Physics A. After the third week in the physics course, sixteen students participated in the second interview, followed by a third interview conducted with fourteen students, one week after the end of the course. Differences in the number of participants interviewed varied slightly, depending on the availability of participants. The participant observations took place over the course of six weeks for approximately eight hours per week in the lab section in which all postbaccalaureate students were enrolled.

The interview sessions were recorded on audiotape and transcribed by the researcher. Data analysis was conducted through the development of coding categories. These categories emerged from the interview transcripts and survey responses, as well as from the researcherís field notes documenting observations, interactions and conversations occurring in lab.

Description of Physics Course

Postbacc students were enrolled in the first of a series of three introductory physics courses. The Department of Physics developed this innovative introductory series as an alternative to a traditional physics class in which memorization of a set of laws and principles becomes the central component of oneís knowledge. Two concepts that have come from the physics education literature and have informed the departmentís physics program are modeling and student-student interaction.

Hestenes (1996) describes how science "involves the construction, validation and application of scientific models, so science instruction should be designed to engage students in making and using models" (p. 1). In the curriculum proposed by Hestenes, he attempts to correct many of the weaknesses of the traditional lecture-demonstration method of physics instruction. His aim is to avoid "fragmentation of knowledge, student passivity, and the persistence of naïve beliefs about the physical world," (1996, p. 6) by having students construct mental models as opposed to memorizing formulas and doing repetitive calculations.

Hestenes view of the importance of the construction of mental models is shared by McDermott (1991):

All individuals must construct their own concepts (mental models), and the knowledge they already have (or think they have) significantly affects what they can learn. The student is not viewed as a passive recipient of knowledge but rather as an active participant in its creation. (p. 305)

Physics A strives toward providing students a means and an impetus to wrestle with their own mental models. During the initial portion of the course, students spend multiple discussion/lab sessions constructing and explaining models of heat transfer in a simple system. These explanations are meant to demonstrate to the student the importance of model building as well as how it is done. This same type of model construction is revisited throughout the course with a variety of subject matter. The course offers students the opportunity to actually acquire an understanding of the principles that underlie the words, symbols and equations that comprise an introductory-level understanding of physics. Instead of generating knowledge through memorization in which the learner lacks a significant understanding of concepts, students are immersed in the concepts and engage in active problem solving.

Additionally, exams in the course establish that rote memorization and number crunching will not be rewarded. At least two-thirds of each exam is made up of essay questions in which students are not only expected to provide the correct answer, but also an explanation of that answer. As a result of this form of assessment, students are provided with an impetus and reward for constructing their own mental models.

Another important concept that has been incorporated into the physics course is the use of student-student interactions. Samiullah (1995) investigated the effectiveness of student-student interaction *during* lecture. He discovered through a series of questionnaires throughout the course that these interactions improved student attitudes. Interactions like these are difficult, at best, in the confines of a lecture hall. Physics Aís extensive use of small groups in discussion/lab provides students with a more comfortable and natural environment, which enables them to freely interact. During lab, students are nearly always engaged in small lab groups composed of four to five students. These groups are constantly interacting in small discussions centered around lab activities that focus less on calculation and more on student problem solving. By providing students with opportunities to struggle with physics lab problems in small groups, students are more likely to begin constructing mental models of the physical world as opposed to regurgitating memorized facts.

The philosophy underlying Physics A supports a structural difference in the design of the class. During the six-week summer session, students spent only three hours in lecture per week, while attending lab for ten hours per week. Lecture is the place where students take quizzes and exams and receive announcements. The lecturer also organizes what takes place during the discussion lab. Unlike traditionally taught science courses, the lecture associated with this physics class is de-emphasized and becomes a small part of the overall course. The lecture is not a means by which students acquire course content. Instead, the laboratory component of the course is the setting in which the majority of student learning occurs.

Another component critical to the learning process in Physics A is the role of the teaching assistant. Instead of being a readily available source for correct answers, the teaching assistant strategically facilitates the studentsí learning process through posing thought provoking questions that encourage students to seek out answers through active involvement in lab experiments and by using one another as resources. Within the context of raising questions for the students, the teaching assistant encourages thinking, rather than focusing on procedural aspects that are common to most traditional lab settings. Instead of providing students with the right answers, the teaching assistant encourages students to probe the issues until they grasp the material. Illuminating the correct answers through challenging questions engages students in a dialogue that leads them to a genuine understanding of physics concepts.

ANALYSIS

The data generated over the course of eight weeks indicated that students changed

their approaches to solving problems as a result of the Physics A. Through researcher observations and results from student interviews and surveys, it was apparent that these students became more effective problem solvers. They were able to work through problems more efficiently and were more likely to do work on problems that moved them in the direction of a correct answer. These positive gains included an increased ability to (a) visualize concepts, (b) understand concepts underlying equations, formulas and definitions, and (c) initially approach problems with a focus on the key information contained within it, rather than on extraneous information. In addition to gains in problem solving skills within the context of the course, postbacc students also experienced some degree of transferability of these skills to problem solving in other academic situations. Students primarily perceived an increase in their ability to apply these skills to MCAT exam questions.

Role of Teaching Assistant in Problem Solving

In order to begin to understand the postbacc studentsí positive gains in problem solving, it is important to begin by examining the role of the teaching assistant. The teaching assistant facilitated student problem solving through asking probing questions that encouraged students to draw knowledge from their active involvement in labs. This technique fostered a student-centered learning environment which valued student input and collaboration as a means to problem solving, rather than instructor knowledge. During lab activities, the researcher observed the teaching assistant using this approach while assisting students in order to facilitate problem solving. Rather than giving students answers to their questions, the teaching assistant wanted students to explore concepts. During a lab lesson early in the course, the teaching assistant was discussing how the equation, $\Delta E_{total} = 0$, tied into an activity on conservation of energy. When students moved into their groups, some students were struggling with the activity and expected the teaching assistant to act as a source for answers when they were unsuccessful on their own. The teaching assistantís role, however, focused on guiding students to answers by illuminating ideas they may want to consider in the problem. When posed with a question about the activity, the teaching assistant responded to students by asking what they think about the problem at hand. Herron (1984) found this method of asking students what they think to be effective. In refraining from giving students answers, the teaching assistant acted as a resource instead of as a reference for correct answers. The teaching assistant wanted to challenge students by pushing them to come to their own understanding of the concepts, especially those core ideas surrounding conservation of energy.

During the lab activity, the teaching assistant described his approach as one that offers a "complete emphasis on thinking, not on procedure." By fielding student questions in lab groups through asking them a question in return, the teaching assistant did in fact create an environment that fostered thinking. Studentsí active involvement and participation in their own learning process contrasts with a traditionalist approach to learning that views the student as a passive recipient of knowledge. If, however, the learning process is to have meaning for students and if they are to grasp concepts beyond mere memorization, studentsí level of engagement with the material must be increased. The prodding approach of the teaching assistant forces students to play an active role in their learning process.

Giving students this room to come to answers on their own encourages a process of discovery that could be a key factor in a studentís academic success and in maintaining student interest and motivation in the course. During an interview, one student, Veronica, expressed that she found the teaching assistantís approach to be a great asset. For Veronica, the fact that the TA " . . . didnít do much as far as teaching, lecturing, explaining - that was good for [her] . . ." Other students, however, were not as receptive to the teaching assistantís approach. Expressing her frustration with the questioning process of the teaching assistant, Grace shared the following comment in an interview: "Heís asking questions and we donít know where heís going. We donít know where heís coming from and weíre trying to teach ourselves more of it, rather than being taught." The core of her frustration came from not knowing if they are right or wrong: " we know if weíre okay but we never get that ëyes, this is how you do ití or ëno youíre thinking of it wrong.í" This need to distinguish between correct and incorrect answers was very strong in nearly half of the postbacc students involved in the third interview. Not hesitating to share how she really felt, Winnie stated: "I hate it when I ask a question and I get a question back instead of answering you because I want to know if Iím correct and it didnít seem like [the teaching assistant] was correcting me. It didnít really help because I never understood if I was right or not - I needed someone to correct me."

Some students had learned to rely heavily on the directives of instructors. As a result, when they were placed in a learning environment in which an instructor does not directly lead them through the material, they were unsure of how to proceed in their learning. This uncertainty manifested itself in the form of frustration in some cases. Students were almost paralyzed by the independent thinking the teaching assistant was asking them to engage in during lab. For some students, their academic careers in the sciences have never challenged them to solve problems on their own, with little intervention from an instructor.

Visualization of Concepts

Through Physics A, students were able to develop visualization skills that allowed them to gain a working knowledge of concepts. Rather than merely memorizing formulas, students were able to see how concepts actually operate. In one lab activity designed to help students understand the difference between rotational and translational kinetic energy, students were involved in an experiment that used a pair of inclined rods. Students rolled a ball down the rods first with a very narrow gap between them, and then with a wider gap. The slope was the same for both trials. When the gap between the rods was wider, the ball spun more on the way down, and it took longer to get to the bottom.

Instead of merely giving students a definition for rotational and translational kinetic energy, the lab activity was designed in a way that actually provided students with a visual representation of the two types of kinetic energy. Students saw that there was rotational kinetic energy as well as translational kinetic energy. The ball that spun more had more rotational kinetic energy, while the ball that spun less had more translational kinetic energy. The effectiveness of merely supplying students with a definition of the concept is quite limited in that it is dependent upon their memorization. Instead, giving students concrete, working examples of the terminology increases their ability to truly understand the material.

In a lab activity designed to introduce students to the topic of pressure, students once again went beyond the mere memorization of a formula. Rather, students were supplied with a working picture of the effects of pressure. A student volunteer was instructed to lie down on a wooden plank that rested on several zip lock bags that were sealed except for areas where a straw was inserted into the bag. Other student volunteers proceeded to blow into the zip lock bags through the straws. The pushing of air into the bags eventually created enough pressure to raise the wooden plank and the student on top of it. Students were able to see and experience firsthand the effects of atmospheric pressure and witness the amount of pressure that was needed to lift the student on the plank. The lab activity acted as a visual aid to complement studentsí conception of pressure. In turn, pressure becomes something that students can conceive of outside of merely knowing an equation for it. Providing students with a working example of pressure enhances student understanding of the concepts.

The extent to which these visual representations of concepts occurred and assisted student learning was evident in student responses on two sets of interviews. Students attributed gains in their visualization abilities to material presented in lab. During the second interview when students were asked about skills they had gained in Physics A, Ben responded, "I am able to imagine whatís going on. Picturing whatís going on - this helped in the class if you could imagine the system - some type of graphical image, itís easier to understand the system." Ben went on to compare the course with other times in the past when he had been taught about energy:

> In the past weíve studied energy is conserved. In [Physics A], with energy conserved, they actually *show* where the energy is going from one place to another place. Before the idea of energy is conserved, people might not feel comfortable because they donít see why itís conserved - they canít picture it.

When asked the same question, Amy provided a similar example of her visualization skills before and after the course: "I can see potential or kinetic energy happening; I can see where itís going whereas before I could insert it into an equation and figure it out, but who cares where itís coming and going." Rather than confining student understanding of conservation of energy to words alone, Physics A expands studentsí

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knowledge base to include visual depictions of fundamental concepts. By appealing to a variety of student learning styles, the course addresses the needs of a cross section of students.

Understanding Concepts Underlying Equations & Formulas

Although early in the course the majority of postbacc students expressed a need to know formulas, Physics A gave students an understanding of formulas that went beyond mere memorization. During a computer lab activity, students viewed a working model of the first law of thermodynamics. Rather than just giving students the relevant formula

$\Delta U = q + w$ to show that a change in internal energy is tied to heating up a given quantity and applying work, students actually derived the formula from watching a closed container of gas particles getting compressed. The computer simulation aided in studentsí visualization of the first law of thermodynamics. Holding off on giving students the formula until after they came to an understanding of the concepts behind it allowed them to synthesize the ideas underlying the formula and the building blocks involved in the formula before memorizing and applying it. At the same time, delaying giving students a formula appeared to heighten studentsí interest in the material since there was an unknown equation they were working toward. Having an opportunity to see the first law of thermodynamics actually operating, before being presented with the formula instilled a sense of challenge into the learning task. Students who perceive the opportunity to make gains in their learning through deducing information from the given situation, in this case the computer simulation, were more inclined to maintain a certain level of interest and motivation in the learning task.

During lab observations it was evident that some students saw the importance of having a keen understanding of the concepts, as opposed to simply knowing formulas. These students expressed a desire to know not only the formulas but also the application of formulas. During lab, Grace contrasted two methods of problem solving. One method entails plugging in a formula to solve for an equation, which she termed as "plug and chug." The second problem solving method she described requires students to "know the parameters surrounding physics questions." Under this problem solving approach, Grace was not satisfied using a formula to come up with a numerical value. Instead, she found a "need to know what the question encompasses," and discovered the importance of "understanding what [sheís] doing." Under these circumstances, the numbers "come naturally to her." A formula proves to be meaningless to Grace unless she can grasp the underlying principles of a problem. Grace seems to identify the key to successful problem solving. She distinguishes between the expediency of using a formula to solve an equation and the concrete knowledge base one can obtain by exploring the fundamental ideas behind a concept. The act of plugging a formula in to solve an equation does not promote an authentic understanding of the material in students Hammer, 1989; Reusser, 1988).

In discussing their experience with using formulas in Physics A, the postbacc students expressed that the courseís emphasis on problem solving and critical thinking helped them to attain a more accurate understanding of what formulas really mean. With the formula $F = ma$, Harold felt that "in [this class] you approach the problem thinking about what is acceleration, how does it affect force; in [this course] you can see the change in acceleration and what happens to force rather than in the classic physics, you basically solve for force." Harold's ability to understand the action behind the formula influenced his ability to understand concepts. He used this strength to act as a resource for other students in his lab group; Harold was constantly explaining course material to his peers in concrete ways that showed his genuine understanding of concepts. On one occasion he used a cup of cold water that was collecting condensation on the outside to explain conservation of energy. The physics class encouraged him to see formulas in action.

Edith contrasted the courseís approach to formulas with her prior experience in other physics classes. In her previous physics classes, ". . . theyíll give you a problem and show you how do it, and then theyíll say here are similar problems and you can use the same formula." At no time in this process was the studentís understanding of the formula emphasized. In Physics A, however, "you derive the formula yourself; youíll create a formula because of the way it acts in nature . . . ; you observe, you see what happens, you try to relate what happens into variables." Edith was actively engaged in making sense out of the concepts underlying formulas. Rather than being a passive recipient of knowledge, the course encouraged Edith to go beyond simply manipulating a formula. She learned to develop a working knowledge of a formula as a result of grasping the concepts behind the formula.

When students were asked on an anonymous survey what they felt they were getting out of Physics A, one student wrote, "I am learning to rely on my understanding of the laws of nature to solve a problem. I am doing more inductive reasoning than I have in any other physics class." This perspective stands out because it shows a student actively reflecting on changes in how he or she approaches solving problems. Not only are the postbacc students immersed in new ways of going about problem solving, they are also stepping back to actively reflect on the changes in their learning and approach to problems. Rarely do students stop to examine the changes they make in their problem solving strategies and realize that they are using a novel approach grounded in logical induction.

Understanding Concepts Underlying Definitions

In addition to understanding concepts behind equations and formulas, students also realized that there was more to physics than memorizing the definitions of terms; knowing what was behind the definitions was more important. During a lab activity on heat capacity, students were introduced to the concept of modes. Students learned that modes are places to put energy. Harold recalled that "before I had just memorized the definition of heat capacity." In previous physics classes, knowing that heat capacity is the amount of heat transferred or temperature change there is for a particular system was enough information. In Physics A, however, Harold learned that ". . . heat capacity depends on how many modes are in the system and the number of modes determines heat capacity." The course ". . . goes into [the] reason behind heat capacity rather than before [you] just remember latent heat capacity and hope you remember." One student reflected in the written survey, "Usually, I get physics problems right, but for the wrong reason. Now I am learning the reasoning correctly." There appears to be a significant difference between what students perceive they need to know in a traditional physics class versus the knowledge that was fostered in the postbacc students in Physics A. The memorization of a definition and calculating a correct numerical quantity was the type of knowledge some postbacc students viewed as important in a physics class. Students, however, realized that a genuine knowledge of the concepts behind the definitions encouraged by Physics A, facilitated a concrete understanding of the material.

The use of energy interaction diagrams was another method used in the course to encourage students to look beyond definitions. During lab, the energy interaction diagrams provided students with a visual representation of how energy is conserved and assisted student understanding surrounding energy conservation and energy changes. For example, one Question/Problem (QP) asked students to draw two energy interaction diagrams in order to show the energy changes when a block of ñ10 degree ice is warmed up, then melted. In another case a student was able to see beyond a mere definition of the first law of thermodynamics. Craig described the energy interaction diagrams as, "more of a way to see it than to say it." Students could actually trace the flow of energy through a system and follow it as it moves through many stages. Before taking the physics course, knowing the definitions of concepts may have directed students to correct answers without ensuring they grasp an understanding of how concepts operate. Craigís comment taps into the importance of grounding the knowledge one can articulate in a visual model that represents the concepts, thereby ensuring that students have a comprehensive understanding of the material.

Approaching Problems

During observations of postbacc students completing problem sets in lab, there were a number of strategies they employed that allowed them to become better problem solvers during the course of the class. These refined problem solving skills enabled them to gain a concrete working knowledge of physics concepts. Additionally, students became more efficient problem solvers through a developing a keen awareness of the key elements involved in solving a problem and focusing their time and energy on those factors. The researcher focused observations on two areas: studentsí initial thought process when confronted with a problem and the specific strategies students utilize in solving problems.

There were several things students did when they faced a seemingly difficult problem in lab or on a QP. One strategy students used when first faced with a challenging problem was utilizing information embedded in the problem. At the beginning of the physics course, some students fell into the trap of looking at a problem and then immediately trying to access any related information in their mind, instead of primarily focusing on

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the problem at hand and critical information within the question itself. The researcher observed attempts at problem solving that were hampered when students did not realize that the information they needed to solve a problem was embedded in the question. One lab group spent at least forty minutes trying to work on a QP but made little progress from their efforts. After some probing from the teaching assistant, the students realized that the information they needed was within the QP. By the end of the course, the students had developed their ability to channel efforts into the features of the problem and its related information that are relevant to formulating a solution, allowing them to focus on the question at hand when beginning to solve problems

Refraining from incorporating too much background knowledge into problem solving was another strategy students developed when approaching problems. During lab observations it appeared that this background knowledge interfered with studentsí ability to progress through certain concepts critical to solving a problem. Instead of examining a problem in a straightforward manner, many students claimed that they "think too much." As a result, they often doubt their initial responses to problems because they try too hard to access their background knowledge and somehow use it to solve the problem at hand. For example, while covering the role of energy in forming and breaking bonds, a lab activity attempted to teach students that energy must be added in order to break bonds. During the activity, Edith used her knowledge of biology to convince her lab group that energy is released when bonds are broken. She recalled from her memory of biology course work that ATP, a molecular compound used to store energy, is made when bonds are broken. Her background knowledge interfered with her ability to grasp the concept being taught in the activity. This demonstrates that drawing from pre-existing knowledge that is unnecessary or irrelevant to solving the problem at hand could derail a student as he or she works through a problem. More experienced problem solvers are better able to identify this irrelevant information (Mohapatra, 1987).

Another problem solving strategy used by at least two postbacc students was putting themselves in the situation of the problem when trying to understand the question. During a lab activity covering dynamic fluids, a group engaged in a general discussion of pressure. The backbone of the question focused on how an energy system balances itself out. Winnie reminded the group that as velocity increases, pressure decreases. In order to clarify this, she described how a tornado works. She shared this concrete example with her group by using a strategy that she identifies as "[putting] herself *into* the question." This process includes "doing the experiment in [her] mind . . ." and trying to ". . . visualize it." Similarly, during an interview in which Frank compared his previous approach to problem solving with what he currently does, he states: "Now itís more of a let me put myself in this situation - whatís going on." Evidently, this process was valuable for both of these students. By personally involving themselves in their problem solving, they were more inclined to connect to their work. This act of immersing oneself into a problem may have given students a closer association to their work. If students are able to maintain a high level of involvement in their problem solving, the motivation and perseverance they have in completing their work could be positively affected.

Student Perceptions of the MCAT

Before closely examining student perceptions of the MCAT, an overview of the exam is important. The MCAT is a four and three-quarter hour test composed of four scored sections: (a) verbal reasoning, (b) physical sciences, (c) writing sample, and (d) biological sciences. The Verbal Reasoning, Physical and Biological Sciences sections contain multiple-choice questions. Verbal Reasoning questions ask students to evaluate information and arguments presented in text passages. Similarly, most of the questions in the Physical and Biological Sciences sections accompany brief informational passages; a smaller number are independent of any passage and of each other. Questions assess knowledge of basic concepts in biology, chemistry, and physics through their application to the solution of science problems (Association of American Medical Colleges, 1993).

Verbal reasoning, physical sciences, and biological sciences are each scored on a scale ranging from 1-15, with a 15 as the highest. The number of multiple choice questions answered correctly per section produces a raw score. The raw score is then converted into a scaled score, which falls within the fifteen-point range. Many students take the MCAT multiple times, and, according to the Association of American Medical Colleges, it is rare for students to improve their score by more than two points unless their initial scores are less than a three on a given test. (Association of American Medical Colleges, 1998).

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Since their enrollment in Physics A was part of their program of study in the postbacc program, a number of students initially viewed the course as direct preparation for the MCAT. In the written survey distributed to students at the end of the second week in the physics course, a question inquired about the extent to which studentsí expectations for the class have been met. One studentís comment reflected studentsí dependence on the physics course for MCAT preparation: "We have one month before the MCAT and have only reviewed one or two of the many topics that we will need to know." Knowledge of key formulas for the exam was the area students deemed most important in their test preparation and they looked toward the physics class as a means by which to review formulas for the MCAT. In several conversations and interactions with postbacc students, they expressed to the researcher a sense of urgency for knowing the formulas they believe will help them on the MCAT. Traditionally, the majority of students participating in the postbacc program have focused their test preparation efforts on memorization of formulas and test taking strategies. Therefore it was no surprise that this group of postbacc students had a preconceived notion of the type of knowledge the physics class was going to impart.

By the end of the course, however, students found that Physics A was not designed as a test preparation class geared for teaching to exam questions, and, more importantly, oneís ability to answer MCAT questions was not based on rote memorization or cursory knowledge of scientific content areas. These perceptions were shared by students during the third interview with the researcher, only a few days after they took the MCAT. When asked to reflect on the type of MCAT questions they encountered, some students shared the following impressions:

> "I expected much more calculation and it seemed to be very conceptual - a lot of questions that were conceptual."
>
> "You really couldnít go on what you knew already - it was 70% from passages, 30% from your knowledge."
>
> "It was difficult because it wasnít like all the other MCATs; it was mostly conceptual so it had all this stuff that you really couldnít study for."
>
> "It was hard because this time they would ask a lot more of those questions . . . not really equations where you need a formula, more like concepts - you needed more concepts. It made it difficult for me because in the past it was not like that; it was more like you now the formulas, use them. Now itís more conceptual."

"You have to think your way through. You canít go from knowledge that you have."

"You need to know the way things work."

Postbacc studentsí impressions of the MCAT questions highlight the conceptual knowledge the exam expects them to employ. The de-emphasis on using formulas is replaced by the need for a working knowledge of the principles underlying formulas.

The discrepancy between the skills and problem solving abilities postbacc students initially thought they needed and what they actually need for the MCAT emerges as a concern. The postbacc program struggles to deal with this predicament. The problem solving and critical thinking skills students develop in the physics course are applicable to the MCAT. However, what remains to be addressed is reconciling studentsí initial perceptions of the MCAT and what they actually need to know to perform well on the exam.

Student Application of Physics Problem Solving Skills on the MCAT

Students found the most success in transferring two problem solving techniques they obtained in the physics class to the MCAT: visualization of processes and utilizing information embedded in a problem. During the third interview, when asked what she did on the August 16th MCAT that she did <u>not</u> do before taking the physics course and on her first attempt at the MCAT, Amy replied, "I was visualizing concepts, I could see

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it, whereas before I would just know hot air is less dense than cold air . . . but I wouldnít understand how that would apply." Amy attributed her newly found visualization skills to lab. She found that the hands-on experiments made concepts come to life and enabled her to see how everything is working in the real world. Evidently the ability to visualize a concept directly affected studentsí depth of understanding of the material. If studentsí comments are accurate and the MCAT emphasized conceptual knowledge, then using visualization as a means to understanding systems and concepts could aid students in their problem solving. Amyís application of visualization skills from the physics course may have positively affected her performance on the MCAT. Her scores on the physical sciences and biological sciences sections of the exam increased by two points when her score prior to taking the physics course are compared to her score following the physics course.

Studentsí ability to maximize their use of information embedded in a problem as a tool for coming to an understanding of how to work through and solve a problem was another skill students perceived they obtained from Physics A and later applied to the MCAT. While reflecting in the third interview on skills he utilized on the MCAT that may have been obtained from the physics course, Mark said relying on the question alone and not being sidetracked by everything that pours into his mind related to the problem was an effective strategy. Markís score on the biological sciences section of the MCAT, however, was unchanged after taking the physics course while his physical sciences score went down by one point. Markís MCAT scores prior to entering the program, however, were the highest out of all students enrolled in the postbacc program. Therefore, it is not surprising that his scores did not increase.

After taking the MCAT Maya reported using a similar skill from the class during problem solving. The courseís lab "forced [her] into looking at the whole picture instead of just part of the picture, a lot of times [she] would look at a question and [she] would only think of the most obvious types of energy." Mayaís MCAT performance may have been strengthened by utilizing this problem solving strategy as seen by the three point increase on both the physical science and biological science sections. Honing in on important information within a problem decreases the likelihood that students will get sidetracked into drawing from irrelevant and extraneous information given in a problem.

Detecting the data that was pertinent to working through questions, facilitated studentsí problem solving by them more efficient problem solvers.

The extent to which problems can be used as a resource was most strongly experienced by Frank on the MCAT, who received the highest letter grade in the course. During the third interview, Frank shared that the skill used on the physical sciences section of the MCAT that he may have obtained from the physics class was "thinking a lot more about the question instead of wasting time looking into his memory bank for [a] formula." He identifies this strategy as ". . . more of a skill where trying to deduce the answer from the question . . ." was effective whereas, ". . . before it was ëokay theyíre asking me a question like this, Iíve seen a question like this before, I have to think of the formula I used back then.í" Frankís MCAT score on the biological sciences section of the MCAT increased by two points following Physics A.

CONCLUSION

Physics A has the potential for far reaching effects on postbacc students. Through their involvement in the class, students made strides in their problem solving abilities and use of a conceptual framework for understanding course material. These advances have impacted the postbacc students in areas outside of their success in the class. Problem solving strategies students gained over the course of six weeks were immediately transferable and beneficial in other academic contexts, specifically the MCAT. Ongoing observations of students in study groups are being made to collect evidence that the students are continuing to apply these skills in upper division science courses in which they are enrolled. A comment regarding student performance on the MCAT is in order here. Previously, the postbacc program has been able to help students to an average score increase of 1.5. However, this year the average changes in scores on the test were around 0.7. This is being attributed to the fact that this is one of the two strongest classes, academically, that the program has had. The program focus on improving basic study and test-taking skills and puts secondary emphasis on content review during the summer program. Students seem to be able to achieve scores of seven or eight on the MCAT after the program, regardless of whether they started with a three or a six. Thus, by having a strong class this year it has been difficult to achieve a large average score

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increase. However, more students were able to achieve gains of two and three points than in years past, and further experience with Physics A will be necessary to determine the extent of the benefits from the course for postbacc students.

Unlike traditional course work in physics, Physics A pushed students to gain an understanding of concepts that goes deeper than a surface level grasp of laws and principles or a calculation of numerical values. Studentsí active engagement in thinking about the underlying principles of concepts was complemented by an approach to problem solving that was more efficient and effective. The lab component of Physics A served as the setting for this powerful learning and an arena in which course material came to life in a way that allowed students to gain a concrete working knowledge of concepts. Students were immersed in a physics curriculum that emphasized thinking, rather than memorization. This learning environment encouraged students to take on an active role in their learning process through constructing their own meaning and knowledge. Lab activities fostered conceptual thinking and problem solving skills that students could access in contexts outside of the physics class.

This study has focused on a select group of students and their experiences in one classroom. Although this could prove useful to people working with similar students, it is important to point out more general insights that could be of wider interest to the science education community. Unlike many younger students, the postbacc students are capable of reflecting on their learning and analyzing it for changes. This allows for a unique glimpse of the effects of an intervention. In this instance it highlighted the studentsí changing abilities to visualize problems, organize and focus on relevant information, apply newly learned problem solving strategies to new contexts, and to learn underlying concepts and perceive connections over memorizing equations and formulae. In any curriculum reform effort it is important to take into account how the students incorporate the new material and learning strategies above and beyond improved performance on various assessment measurements. It is hoped that others could profit by these studentsí ability to articulate their experiences and can use this information to help fine tune their own programs.

These are the initial results in continuing research on using Physics A as an element of the postbaccalaureate program; work will continue this summer. This study has provided snapshots of the studentsí problem solving and critical thinking abilities before and after the first course in the Physics A series, and it has refined themes the authors initially believed worth exploring as well as presenting new issues to explore. The next step will be to take a more detailed look at the process of change in these students, capturing the intermediate phases of development of the thinking skills that come from the course. Additionally, further research will increase the number of students so that there will be a sufficient sample on which to perform a quantitative analysis of MCAT gains for these students.

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