AC 2007-53: COMPARISON OF STUDENT LEARNING IN CHALLENGE-BASED AND TRADITIONAL INSTRUCTION IN BIOTRANSPORT ENGINEERING CLASSROOMS

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Professor Diller earned a Bachelor of Mechanical Engineering degree cum laude from Ohio State University in 1966, followed by a Master of Science in the same field in 1967. He was awarded the Doctor of Science degree, also in mechanical engineering, from the Massachusetts Institute of Technology in 1972. After spending an additional year at MIT as an NIH postdoctoral fellow, he joined the faculty of the College of Engineering at the University of Texas as an assistant professor and has progressively been promoted to his present position. He has served on the editorial boards Cryobiology, Intl. J. Transport Phenom., Cell Preservation Technology, Cryo-Letters and editor of the ASME J. Biomechanical Engineering, and currently is associate editor of Ann. Rev. Biomedical Engineering. He is a Fellow of ASME, AAAS, AIMBE, and BMES, has been president of The Society for Cryobiology, vice-president of the International Institute of Refrigeration and Chair of the Bioengineering Division of the ASME. He is also recipient of the ASME Heat Transfer Memorial Award for career accomplishments in biomedical heat transfer, the ASME HR Lissner Award for career accomplishment in biomedical engineering, and has been an ASME Distinguished Lecturer.

Comparison of Student Learning in Challenge-based and Traditional Instruction in Biotransport Engineering Classrooms

Abstract

This paper compares student learning in challenge-based and traditional engineering classrooms from the perspective of adaptive expertise. Collaborating learning scientists and biomedical engineers designed and implemented a challenge-based method of instruction that followed learning principles presented in the National Research Council report "How People Learn" (HPL). The study was conducted in four different classrooms at three different Research I institutions (2 HPL and 2 traditional classrooms). A pre- and posttest measured knowledge acquisition in the domain and development of innovative problem-solving abilities. HPL and traditional students' test scores were compared. Results show that HPL and traditional students made equivalent knowledge gains, but that HPL students demonstrated significantly greater improvement in innovative thinking abilities. We discuss these results in terms of their implications for improving undergraduate engineering education.

Objectives and Theoretical Framework

Although the engineering knowledge base has advanced immensely over the past century, the way engineering is taught in college classrooms has changed very little. Most core engineering classes are still taught in the traditional lecture style classroom with weekly problem sets and periodic in class quizzes and exams. Students who have learned to be successful in the traditional style are able to master the core content knowledge during the given course. The weaknesses of the traditional model are poor retention, lack of connectedness of the knowledge, and lack of the ability to apply this knowledge to new contexts. Hatano and Inagaki classify this type of inflexible and unconnected mastery as routine expertise.[5] They classify its opposite as adaptive expertise (AE): a more globally organized, connected, and flexible knowledge base.

The challenge-based method studied here follows the How People Learn (HPL) framework.[2] This framework proposes that learning environments should be knowledge centered, community centered, assessment centered and learner centered. Research has shown that the HPL method shows advantages in the development of AE.[4,9,11] In experimental studies in biomechanics and bioengineering ethics, HPL students developed more adaptive expert-like behavior along with equivalent levels of knowledge than students taught with traditional pedagogical methods.[6,7,8,12] While these are promising results, these studies covered only one or two instructional modules. Based on these studies, a more robust investigation of the relative outcomes of HPL and traditional instruction is needed. In this paper, we report on a study that compared the two methods over an entire course in biotransport as taught at multiple institutions via HPL and traditional formats.

Methods

Participants

A total of 136 students consented to participate in the study, of which 106 completed both the pre- and posttests (54 in the HPL condition and 52 in the traditional condition). Most of the students were juniors or seniors in Biomedical Engineering. The gender of the students was obtained with a demographic survey that was completed by 58 of the HPL students and 48 of the traditional students. Among the HPL group were 18 women and 40 men and the traditional group were 13 women and 35 men.

Instructional Methods

The biotransport courses covered all three areas of transport phenomena: momentum (fluids), heat, and mass transfer. The two traditional courses were taught at different institutions. Both courses followed a traditional lecture style with weekly problem sets and periodic in class quizzes and exams.

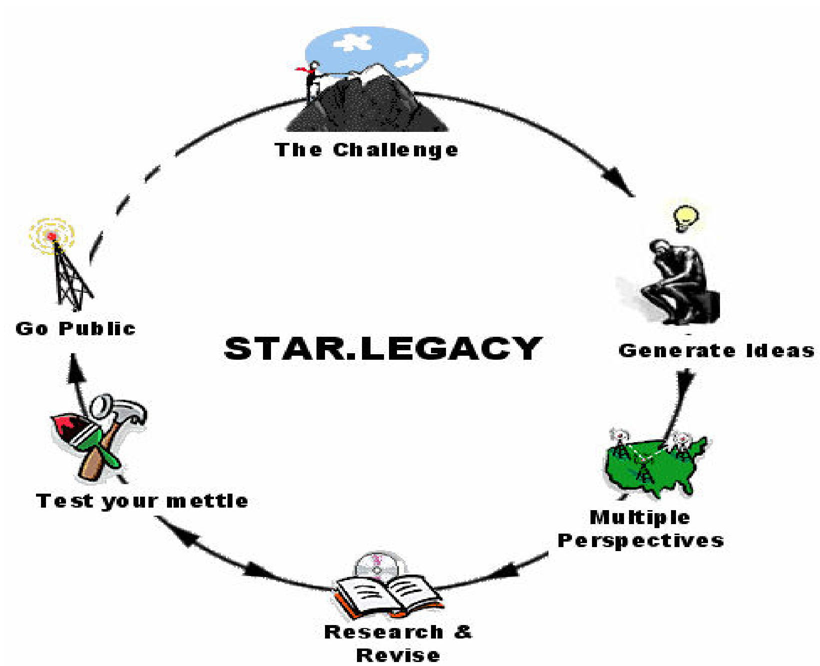

Figure 1. The STAR.Legacy (SL) Cycle

The two HPL courses were taught at different institutions. The professors collaborated prior to the study to design the challenges, but the classes were taught independently of each other. The HPL courses consisted of 10 to 13 challenges. The challenges were delivered following the STAR Legacy Cycle[10] (See Figure 1.) The Legacy Cycle has six phases: the Challenge, Generate Ideas, Multiple Perspectives, Research and Revise, Test Your Mettle, and Go Public. Generate Ideas is a brainstorming activity designed to elicit students thinking about what they will need to know to solve the challenge, what they already know, and what resources they might use. This engages the students thinking prior to the Multiple Perspectives phase where they listen to a lecture, read text, or obtain information from some other form of media. In the Research and Revise phase, students are encouraged to use the information they gained in the Multiple Perspectives phase to revise their own thinking and ideas from the generate ideas phase and consult more resources to help them solve the challenge. The Test Your Meddle phase acts as a formative assessment to help students monitor their own understanding. In the Go Public phase, students report and validate their findings in some form to the rest of the class. This can be in the form of an oral presentation, poster, or a letter to an official (which may not be group oriented).

Study Design

This study was conducted in four different classrooms at three different Research I institutions (2 HPL and 2 traditional classrooms). A pretest/posttest design was used to measure student learning. Each instructor was given a protocol to follow to maintain consistency across research sites. The test consisted of two parts. First, the general knowledge section consisted of 6 multiple-choice questions. These questions did not cover the entire taxonomy but were representative of what students finishing a biotransport class should know. The second section of the test presented the innovation question. This question drew on the basic, foundational principles of the course, but was designed to be too complex for students to fully solve in the allotted time. As we will describe in the coding section, this question is innovative because the correct solution requires students to develop an approach to a novel problem they have not considered previously. The students were given 10 minutes to complete the knowledge section and 15 minutes to complete the innovation section. Students were not allowed to use their notes, textbooks or any other outside resources.

Coding

Knowledge Section

The knowledge section was scored based on accuracy only. The score was the number of multiple-choice questions out of 6 answered correctly.

Innovation Section

The coding system for the innovation section is based on how experts solve problems. Experts tend to address problems initially from a global perspective to understand the primary issues of importance and then move toward developing specific equations or other solution methods.[3] To capture this characteristic, we examined two facets of student performance on the innovation test. The first we refer to as innovation. The innovation score reflects how effectively students are able apply their knowledge base and analysis tools to devise a wise strategy for solving a difficult open ended problem they have now encountered previously. The second facet we refer to as efficiency. This score examines whether students applied appropriate governing principles and constitutive equations to model the process. A high score on these two categories indicates that a student is approaching the problem similarly to an expert in the area who was considering how to solve the problem for the first time. These coding schemes were developed a priori based on coding from earlier experiments.

We arrived at these two scores by a two-step process. First, student solutions were coded using a rubric of 5 categories (See Table 1). The categories were: (1) a picture or diagram to define the system, (2) a written description of the system, (3) identification of system interactions with the environment, (4) a statement of the governing conservation principles, and (5) an application of transport constitutive equations.

Table 1. Coding for Innovation Scores.

Code	Diagram	Written System	Interactions	Governing Principles	Constitutive Eqn
0	absent	absent	absent	absent	absent
1	Picture present but missing heat exchanger	Description present but missing heat exchanger	Incorrect interactions	Incorrect governing principles	Incorrect constitutive equation(s)
2	Heat exchanger present but other aspects missing	Heat exchanger, fuel source, patient are all included in the system	One or more but not all (of 3) interactions: correct heat transfer to the blood, heat transfer from the fuel and heart as pump	Conservation of energy <u>or</u> momentum only	One or more but not all (of 4)correct: heat source from burner, convective exchange to blood, force of pumping, F>flow resistance
3	Heat exchanger, fuel source, patient all present	System is heat exchanger, that interacts with butane and person	All 3 correct	Both conservation of energy <u>and</u> momentum	All 4 correct

Each category was coded on a 4 point scale (0, 1, 2, or 3). A response was coded as a 0 if the category was missing from the student solution. A score of 1 was given if the students did some work that was in the coding category but was primarily incorrect or irrelevant to the problem they were given to solve. A score of 2 covers a wide range, including if some of the necessary information was incomplete, or some the information was incorrect. A score of 3 was given if all the information was present and correct. Table 1 shows the specific elements the solutions needed to include to obtain points.

Next we combined categories to create the innovation and efficiency scores. First, we assigned students a revised score (the system score) which was the higher of the two scores for diagram or written system definition. Our interest was in whether the students attempted to define an explicit system for analysis. Consequently, we counted system descriptions executed in either words or drawings. Then, we computed the innovation score by adding the system score and the interactions score. Next, we computed the efficiency score by adding the governing principles and the constitutive equation scores. The range for each score was 0-6.

Reliability was established between two independent coders on a random sample of 30 of the tests (10% of the sample). The raw measure of inter-rater reliability was 0.92. After reliability was established the remaining exams were coded by the primary coder.

Results

Knowledge Section

We computed a total score, which was equal to the number of the multiple choice items students answered correctly (0-6). We analyzed these data using a 2 x 2 repeated measures analysis of variance (ANOVA) on the knowledge problem scores with time (pretest vs. posttest) as the within subjects factor and instructional treatment (HPL vs. traditional) as the between subjects factor. All of the students improved on this multiple choice test over time (pretest $M = 3.08$, $SE = .11$; posttest $M = 3.53$, $SE = .10$), $F(1, 104) = 11.13$, $MSE = .93$, $p < .001$. There were no other significant effects.

Innovation Section

We examined two measures for the students' performance on the innovation section of the test: innovation and efficiency. We measured these aspects separately so that we could examine these two aspects of AE.

Innovation. We conducted a 2 x 2 repeated measures ANOVA on innovation score with time (pretest vs. posttest) as the within subjects factor and instructional treatment (HPL vs. traditional) as the between subjects factor.

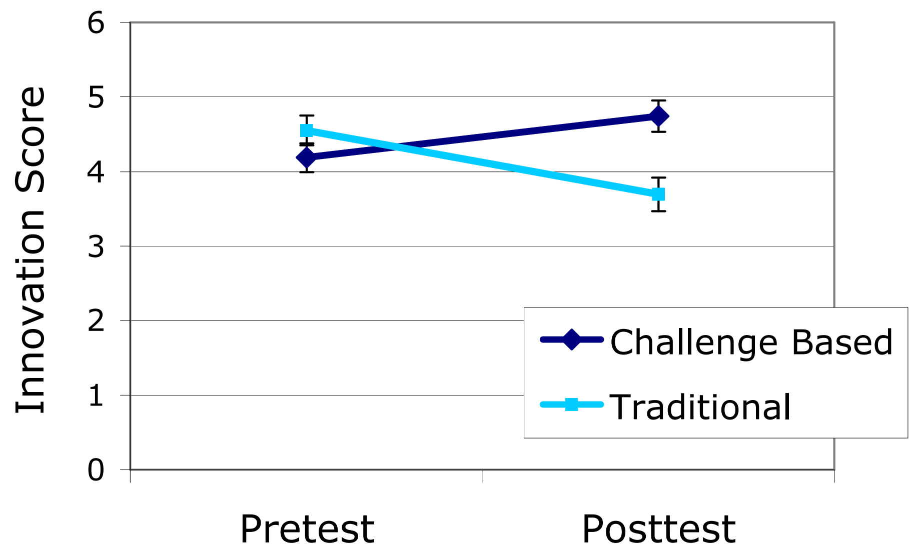

Figure 2. Innovation Scores

The two groups developed innovation differently (See Figure 2). There was an interaction between time and instructional treatment, $F(1, 101) = 14.66$, $MSE = 1.75$, $p < .001$. Post hoc tests confirm what Figure 2 demonstrates regarding the meaning of this interaction. The two groups' scores on the pretest were not different. However, the HPL group scored significantly higher than the traditional group on innovation score on the posttest ($p < .01$). The HPL group's scores significantly increased from pretest to posttest ($p < .05$) while the traditional group's scores decreased significantly ($p < .01$). There were no other significant effects.

Efficiency. We conducted the same repeated measures ANOVA analysis to examine the efficiency scores as we had with the innovation scores. Efficiency scores improved over time (pretest $M = .84$, $SE = .10$; posttest $M = 1.47$, $SE = .14$), $F(1, 101) = 15.71$, $MSE = 1.32$, $p < .001$.The HPL group ($M = 1.60$, $SE = .12$) scored higher than the traditional group ($M =.70$, $SE = .13$) overall, $F(1, 101) = 25.46$, $MSE = 1.63$, $p < .001$. Furthermore, the two groups performed differently on efficiency on the two tests (See Figure 3). There was a significant interaction between time and instructional treatment, $F(1, 101) = 34.53$, $MSE = 1.32$, $p < .001$. Post hoc tests confirm the patterns Figure 3 shows. While similar on the pretest, the HPL group scored significantly higher on efficiency on the posttest ($p < .001$). Moreover, the HPL group improved significantly from pretest to posttest ($p < .001$), while the traditional group did not change significantly. This effect also reveals that the main effect for time was likely due to the HPL group's improvement on efficiency, as the traditional group did not contribute to this improvement.

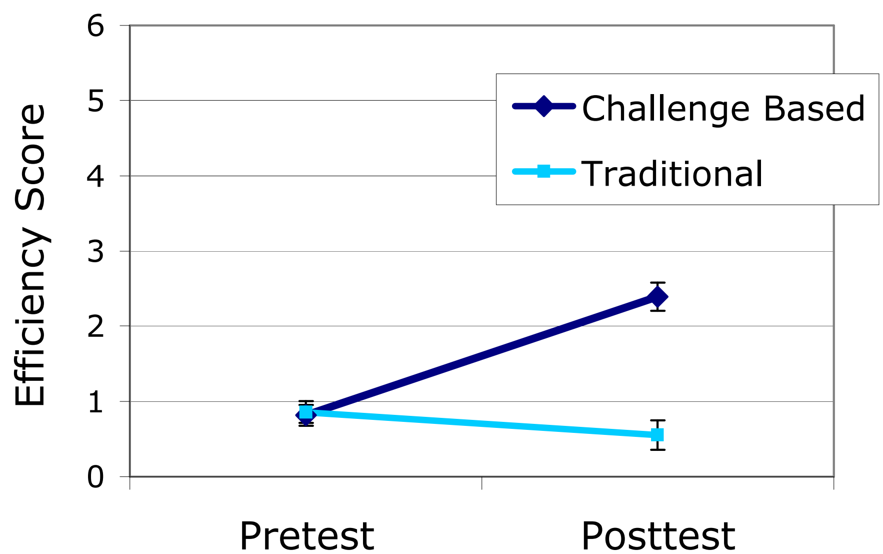

Figure 3. Efficiency Scores

Conclusions and Educational Importance

The HPL method of instruction facilitated basic knowledge acquisition in biomedical engineering students similar to traditional methods, while showing significant added value in promoting students developing innovation. Thus, the HPL framework of learning is more effective and better suited to undergraduate engineering students developing AE skills that will serve them well in future professional endeavors. In light of current ABET guidelines for program outcomes and industry calls for more innovative engineers; this result is encouraging and significant.[1] We believe these results can be generalized to education in other professional disciplines where content, innovation and flexible knowledge application are necessary.

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