AC 2010-505: LEARNING THROUGH REVERSE ENGINEERING

Shannon O'Brien, Manhattan College

J.Patrick Abulencia, Manhattan College

Learning through Reverse Engineering

Abstract

Engineering students have always practiced the skill of problem solving by repetition. Professors would assign problem after problem for students to attempt, struggle, and hopefully learn. Although practice through repetition is a viable method to improve student ability, many still have difficulty.

Cognitive psychologists have identified several traits of "expert" problem solvers. First, experts are known to be skilled in recognizing familiar patterns. Second, they mentally represent problems largely in terms of underlying principles. Finally, experts plan solution strategies, and detect constraints given in the problem statement. To incorporate these ideas into engineering education, a project called "Reverse Engineering" was created, and employed in a sophomore fluids mechanics class. No different than taking a piece of equipment apart to better understand its operation, students can apply the same approach to chemical engineering problems. Briefly, students were asked to generate their own problems related to a concept discussed during class, and present the solution by breaking it down into its fundamental parts. We hypothesize that students would improve their problem solving ability by dissecting problems in this manner, through cognition of underlying principles and patterns used in working towards a solution.

To this end, two student populations with similar GPAs were assessed over consecutive years. The first group (Group 1) participated in the standard curriculum, while the second group (Group 2) participated in the standard curriculum with the addition of the Reverse Engineering assignment. This assignment was executed between the second and third exams of the semester. To establish the "pretreatment" condition, scores from the second exam were compared between both groups. Statistical hypothesis testing indicate that there is no significant difference between them (i.e. Group #1 mean = 78.32, while Group #2 mean = 81.94). In contrast, comparison of the third and final exams between the two groups reveals a statistically significant difference (i.e. Group #1 mean = 73.8 and Group #2 mean = 83.02 for the third exam and Group #1 mean = 74.15 and Group #2 mean = 83.05 for the final exam) translating to an increase of 12.5% and 14.7% respectively. It is noteworthy to mention that the exams used in this study typically did not produce significantly different scores when administered in previous years, thus allowing us to conclude that they have a similar level of difficulty. The results imply that students who supplemented their learning with the Reverse Engineering technique performed better in a problem based exam compared to those who solely practiced by repetition. Taken together, assignments such as Reverse Engineering can easily be incorporated into any course to help students improve their problem solving skills.

Introduction

In the most basic sense, professors teaching a fundamental engineering course will introduce a topic, demonstrate its application, and assign problems which require its utilization. Through the repetition of these problems, students become familiar with and begin to recognize patterns that indicate when to apply particular concepts. In this way, students are confined to the lower levels of Bloom's taxonomy: knowledge, comprehension, and application. Although the students in the class will grasp the concepts presented in lecture, a deeper level of understanding is not achieved.

Reverse engineering is a technique in which a student learns how a particular piece of equipment works by breaking it down into its fundamental parts. If the analysis is successful, the student will understand the purpose of each individual element contained within the system structure. In this way, he or she should be able to construct their own device which performs the same function and includes all of the necessary components. For example, a mechanical engineering student can learn how a car works by dissecting its engine. If the student fully understands the dynamics of the engine, he or she should be able to design their own and explain the purpose of each part incorporated into their design.

Reverse engineering is not a new concept. In the past, this technique has been implemented in a number of senior design courses[1]. Students are presented with pieces of equipment, computer software, or even chemical processes to be examined. Through this investigation, students attain the knowledge required to design their own equipment, computer program, or chemical plant. Reverse engineering forces students to progress to the upper levels of Bloom's taxonomy: design, implementation, and evaluation.

The application of reverse engineering need not be restricted to these areas nor to senior level courses. Instead, it is suggested that reverse engineering can be applied to problem solving in order to allow students to acquire a deeper knowledge of concepts in their fundamental engineering courses. This provides a stronger base of understanding earlier in a student's college career. Complex ideas from higher level courses can be more easily developed upon this foundation.

Background

Problem solving requires two types of thinking: critical and creative. Critical thinking is convergent and involves the application of accepted principles. On the other hand, creative thinking is divergent and often violates accepted principles by creating new ideas. Problem solving requires the harnessing of both of these skills to obtain a solution. Research has proven that critical and creative thinking skills are synergistic[1]. As a result, an improvement in one will almost certainly help in development of the other.

Typical engineering courses foster the development of critical thinking through repetition of problems, while creative thinking is emphasized to a lesser degree. This is because the development of this type of divergent thinking is a "much more abstract and daunting task for the educator."[2,3]. An assignment in which students are asked to reverse engineer a problem provides a viable means for creative thinking skills development. A project of this type fosters the maturity of both critical and creative thinking, which will inevitably transform a student into a better problem solver. It is important to realize that the reverse engineering presented in this paper is simply an assignment to supplement an engineering course; it is not meant to be a teaching style in and of itself.

According to Felder[4], there are five dimensions of learning: perception, input, organization, processing, and understanding and five corresponding dimensions of teaching styles: content, presentation, organization, student participation, and perspective. For each dimension and preferred learning style, there is a corresponding teaching style. The following table summarizes these dimensions:

Learning Dimension	Learning Style	Corresponding Teaching Dimension	Corresponding Teaching Style
Perception	Sensory	Content	Concrete
	Intuitive		Abstract
Input	Visual	Presentation	Visual
	Auditory		Verbal
Organization	Inductive	Organization	Inductive
	Deductive		Deductive
Processing	Active	Student Participation	Active
	Reflective		Passive
Understanding	Sequential	Perspective	Sequential
	Global		Global

Table 1: Dimensions of Learning and Teaching Styles[4]

Typical engineering professors teach their courses in a way that is abstract, verbal, deductive, passive and sequential. However, "many or most" engineering students prefer learning in a sensory, visual, inductive, active and global style. According to Felder, global learners are "the ones who see the connections no one else sees." [4] This type of learning should be fostered in engineering education, rather than discouraged by solely relying on education through repetition and memorization.

Innovation and sophisticated problem solving skills are the trademark of a thriving engineer. For this reason, creative thinking and development of problem solving skills should be emphasized from the very beginning of engineering coursework. Reverse engineering is a suitable technique that can encourage both of these qualities in order to produce engineers with a deeper and more comprehensive understanding of their field.

Integrated Reverse Engineering

At Manhattan College, a reverse engineering project was employed in a sophomore level fluid mechanics class for chemical engineering majors. In this course, many basic fluid dynamics principles are introduced, including the ever important and fundamental application of the Bernoulli equation. There were two classes assessed over consecutive years: Group 1, consisting of 25 second-year students, and Group 2, consisting of 35 second-year students. Group 1 experienced the standard curriculum of problem solving skill development through repetition. The following year, the course was taught by the same professor to Group 2. These students underwent the standard curriculum in addition to a reverse engineering project implemented between the second and third exams of the semester.

Before this study was conducted, it was necessary to compare the abilities of the two groups in order to ensure that neither group had a predetermined advantage over the other. The basis used for comparison was the average cumulative grade point average of each group at the conclusion of the semester prior to the fluid mechanics course. The independent groups t-test was used to evaluate statistical significance. Group 1 possessed an average GPA of 3.393 with a standard deviation of 0.335, while the GPA of Group 2 was 3.333 with a standard deviation of 0.445. It was concluded from the t-test that the grade point averages were not significantly different from one another, with a 95% confidence level. The two independent groups were deemed similar enough to obtain valid results for this investigation.

In order to further validate that both groups were of equal ability and to establish a "pretreatment" condition, the average scores on the second exam were evaluated. Statistical hypothesis testing indicated that there was not a significant difference between the exam performances. Again, an independent groups t-test was used to evaluate to statistical significance. Group 1 produced an average of 78.32% with a standard deviation of 16.25%, while the mean score for Group 2 was 81.94% with a standard deviation of 10.84%. The t-test confirmed that the groups were not significantly different with a certainty level of 95%.

Three examinations and one cumulative final were administered to each group over the course of the semester. All four exams consisted of approximately three to four problem statements to be completed over the course of two hours. The exam sets given to each group were not identical, but were of equal difficulty. In previous years, each set had been administered and resulted in similar student performance.

In between the second and third tests, Group 2 was assigned a project in which they were required to design a problem related to a topic covered in lecture. Analogous to the reverse engineering technique, students were tasked to break the problem into its fundamental parts in order to present its solution. In the project statement, students were given a brief introduction to the concept of reverse engineering problems and also presented with an example question and answer set, which was prepared by the professor. Students were required to create an original problem, state the given and desired variables, construct a system diagram, and deliver a detailed, narrated solution. Grading was based on technical content (40%), explanation of solution (40%), presentation (10%), and originality (10%).

It was hypothesized that students who completed this assignment would improve their problem solving skills and consequently enhances their performance on subsequent exams.

Results

The measure of success of the integrated reverse engineering project was quantified in the mean scores on the third and final exams. The average scores and standard deviations for the third and final exams are shown below in Table 2:

	Third Exam		**Final Exam**	
	Average	*Standard Deviation*	*Average*	*Standard Deviation*
Group 1 (n = 25)	73.8	20.71	74.15	14.08
Group 2 (n = 35)	83.03	10.82	85.06	9.61

Table 2: Third and Final Exam Comparison

In comparison to Group 1, Group 2 experienced 12.5% increase for the third exam and a 14.7% increase for the final exam. The average for Group 2 over the entire semester was 86.04% with a standard deviation of 7.59%, in comparison to an average of 82.12% with a standard deviation of 7.59% for Group 1; this constitutes a 4.8% difference. Statistical hypothesis testing, using an independent group t-test (95% confidence range), indicated that the results of the third and final exams for each group were significantly different from one another.

The statistically significant increase in the exam averages between Group 1 and Group 2 in the third and final exams confirmed the proposed hypothesis. The reverse engineering assignment produced a significant increase in exam scores, which suggests that the students in Group 2 attained a greater level of understanding of course material than those in Group 1. It is suggested that a reverse engineering project, if incorporated into similar engineering curriculum, will most likely generate comparable results.

A number of the students generated problem sets that demonstrated a superior understanding of fluid mechanics concepts. For example, one of the reverse engineering projects involved a four-part question in which laminar and turbulent contributions to minimum fluidization velocity were analyzed using the Ergun and fluidization equations. The student justified that the Reynolds number can be used to simplify the calculation by neglecting the term, either laminar or turbulent, which did not correspond to the proper regime of flow. In order to validate this notion, the student performed the calculation with and without the simplification, and compared the results by obtaining a percent error. The student made use of an idea presented in class, and attempted to prove its validity.

Conclusion

Systematic evaluation of anything allows for greater insight into its structure and function. Although it is basic in concept, performing the reverse engineering of a problem will facilitate students when they are faced with challenges in the future, which can be in the form of exam problems, interview questions, or even undertakings in industry. A project of this type is particularly beneficial for those students that are more creative in their thinking, as opposed to those that learn via a “cookbook” type of teaching approach.

In this investigation, the reverse engineering project assigned to Group 2 forced the students to improve their thinking in the areas of design, implementation, and evaluation, the three highest levels of Bloom’s taxonomy. Each student created their own problems, and dissected each solution piece by piece into smaller sub-tasks. This enabled the students to more easily recognize patterns, which is one of the traits of an “expert” according to cognitive psychologists[5]. A substantial average increase of 12.5%-14.7% on exams was exhibited, suggesting that the reverse engineering technique was a valuable instrument for educating this sophomore level course. Engineering education should seek to accommodate to a broader range of students, especially those with the ability to think “outside of the box.” Classical teaching techniques for engineering coursework stress the importance of repetition to enforce concepts. However, it has been shown in this study, as well as many others, that reverse engineering is a successful method for educating students in a broad range of topics. This approach allows for critical and creative thinking development, which will enable students to more easily and efficiently solve problems and recognize patterns.

In this study, a reverse engineering assignment resulted in a 12.5-14.7% increase in exam scores. This substantial improvement indicates a greater level of material proficiency, as well as enhanced problem solving ability.

References

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