Enhancing Students' Problem Solving Skills through Integrative Learning

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***Abstract* — Engineering problems can always be solved via more than one method. However, there is often an advantage in choosing a particular method, depending on the specific parameters and constraints. The ability to choose the most appropriate approach to solving a particular problem is a critical skill that needs to be cultivated over time. Starting from lower level courses, students should learn how to approach each problem from various angles, rather than to solve specific types of problems in a "cookbook" fashion. This paper aims to emphasize the importance of integrative learning in cultivating such critical thinking skills in undergraduate students. Integrative learning enables students to establish connections between different topics covered in a course, and link concepts across the curriculum. Two batches of undergraduate students are compared in this paper. Lower level courses were taught in a prescriptive process-oriented method for the first batch. In contrast, the second batch acquired the skills needed to link knowledge across the curriculum, in order to determine the most suitable approach to solving a problem. Assessment data indicates that the latter batch of students were able to consider different approaches and to develop more efficient problem solutions in upper level courses.**

Keywords— integrative learning; inquiry-based learning; knowledge integration.

I. Introduction

Most engineering undergraduate students prefer to follow a systematic approach in solving problems. This is particularly prevalent in situations where the problem is well formulated, and the student is under pressure and time constraints during exams and quizzes to provide the "correct" solution. Homework assignments and projects allow students to ponder more deeply into alternative solution methods, but even then, students' accessibility to solution manuals online, which is arguably unethical, makes it more likely for students to follow a standard approach in solving textbook problems. For each class of problems, the student will follow a pre-defined *cookbook approach* consisting of specific steps, leading to the correct answer.

Despite the fact that the *cookbook approach* has been successfully implemented, its usefulness is limited to standard design procedures, repetitive calculations, and simple problems. For example, Richards [1] argued that engineering design students could benefit from the availability of tables, graphs, and charts in a variety of engineering applications. These tables and charts, along with step-by-step instructions, can provide simplified information, leading to safe designs for a broad range of mechanical components. Cookbook procedures continue to be prevalent in lab instruction [2], mainly due to the need to adhere to standards and specifications, and to the necessity to ensure a safe lab environment. The cookbook approach is often preferred by students with weaker preparation in math and physics, as it provides them with systematic procedures to solve problems and pass exams [3], [4]. It also enables inexperienced instructors to divide the course topics into pieces and segments pieces, which minimizes student questions, as well as class preparation time [5].

Most engineering problems, however, require a certain level of logic, knowledge integration, and critical thinking in order to reach the most appropriate solution. Knowledge integration is a critical skill that can be cultivated in students as part of the learning process. Integrative learning can be defined as a methodology to enhance "the students' abilities to integrate their learning across contexts and over time" [6]. The concept is closely linked to other learning and education frameworks such as distributed cognition, interdisciplinary learning, and curriculum integration. It is, however, distinct in its focus on the individual learner being responsible for knowledge integration. In the famous "barometer question" story, published in various magazines and later popularized by Alexander Calandra [7], a professor asks students in an exam question to determine the height of a tall building using a barometer. The student provides several solutions, none of which entails measurement of atmospheric pressure. In fact, the student relies on earlier knowledge of topics such as pendulum motion, gravitational acceleration, and basic trigonometry to solve the problem.

Integrative learning is built on the premise that there is never a single approach to solving a particular problem. Knowledge, acquired from different sources at different stages of learning, is recalled and integrated into the student's mind to enable them to approach any problem from more than one angle. In its simplest form, within the context of a particular discipline, the student must be able to build upon topics covered earlier, establishing connections between the course topics, and exploring the inter-connectivity among these topics. Examples rooted in basic math and physics include the multitude of methods available to find roots of polynomials, to solve simultaneous equations, and to calculate distances based on trigonometric functions and geometric relations. Analytical, numerical, and graphical solutions represent a range of options available to solve problems. Cartesian, cylindrical and polar coordinate systems can all be used to represent certain phenomena, but depending on the problem at hand, the choice of the most appropriate system will lead to a more efficient and elegant solution. At the more advanced levels, different types of mathematical transforms can be used to convert functions between domains, such as time and frequency. The ability to avoid function fixedness enables the engineering student to explore different approaches to solving a single problem, all of which are correct.

II. Case Study in Electrical Engineering

The case study presented in this paper was designed to evaluate the effect of integrative learning on the ability of electrical engineering students to link various concepts taught, both within a single course and across multiple courses. The first batch received no preparation in earlier courses on integrative learning. Instead, they were taught by professors who mostly followed the cookbook approach. Conversely, the second batch was exposed to integrative learning in three earlier courses, in preparation for the subsequent senior level course.

In this study, a specific definition of integrative learning as a methodology for relating different topics within a single field is considered. This is in contrast with the broader definition of integrative learning, which entails integrating knowledge across different specialties and domains. The study relies on comparing the performance of the two batches of students via various assessment tools, including evaluation of student's performance via classroom observation. The control and treatment batches consisted of fifteen and ten students, respectively, studying electrical and computer engineering.

The first batch, the control group, were not exposed to integrative learning concepts until they reached the fourth year. The second batch, the treatment group, were introduced to integrative learning through three junior-level courses: 1) Probability and Random Variables, 2) Digital Signal Processing, and 3) Communication Systems. Students' performance in relation to their ability to integrate knowledge was assessed in a fourth year course (Control Systems). This course was chosen for assessment because it covers various topics that are inter-linked, and because it does not rely heavily on the topics covered in the earlier three courses, thereby eliminating instructor bias. In order to ensure no bias from the students' overall academic performance, Table 1 provides a comparison between grade point average (GPA) indicators for the two groups. The data indicates no significant difference between the two groups.

TABLE I. Grade Point Average (GPA) Indicators for Both Groups

Indicator	Control Group	Treatment Group
GPA (Average)	3.35	3.29
GPA (St. Dev.)	0.56	0.53
GPA (Max)	3.98	3.90
GPA (Min)	2.37	2.56

During the semester, students learned about modeling of control systems in both time and frequency domains. In addition, among the learning objectives of the course is the design and analysis of various aspects of a control system, such as stability and steady state error. The components of the course were delivered independently, with reference to specific chapters in the textbook. However, during the lectures, the link among the topics was emphasized via examples and class discussion.

III. Results

For both groups, a course project was assigned. Both projects were designed to include mathematical modelling and analysis, in addition to simulation. For the control group, the objective of the project was to study permanent-magnet motors and generators used in high-performance mechatronic systems as a power generating system. The block diagram for the project assigned to the control group is shown in Fig. 1.

For the treatment group, the objective of the project was to study permanent-magnet DC motors and their applications in the field of robotics. Similar to the control group project, this project featured a third-order system. The block diagram for the project assigned to the treatment group is show in Fig. 2.

For both projects, two main tasks were to be achieved. The first task was to derive a mathematical model for the system, and the second task was to use MATLAB / SIMULINK to simulate the performance of the system. One of the key requirements of the project was to study the transient dynamics of the system by keeping track of specific variables.

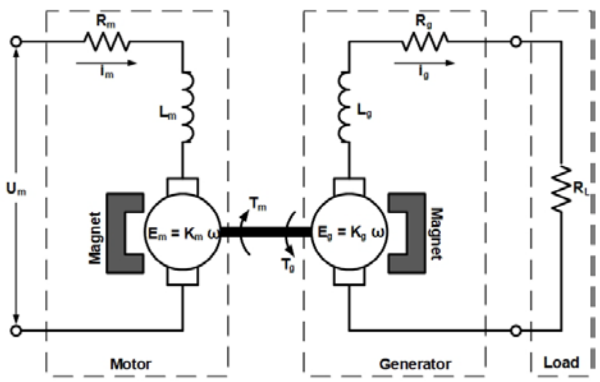


Fig. 1. Block diagram for the project assigned to the control group

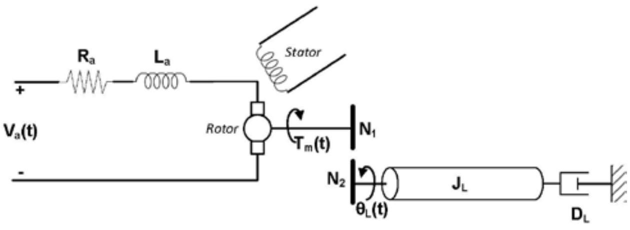


Fig. 2. Block Diagram for the project assigned to the treatment group

Another requirement was to perform the steady-state analysis for the system and derive its overall transfer function. Both projects were assigned to the students during the last month of the semester, and both groups of students were given three weeks to complete the project. The projects required the students to start by deriving a set of differential equations that relate the different variables. The students were then expected to keep track of specific variables and find the transfer function.

Despite the similarity between the projects, the control group struggled with their project while the treatment group managed to complete the project with more ease. Students from the control group required a lot of guidance, and could not easily relate the project to the course content. Many class discussion and office hours visits regarding their project resulted from the control's group inability to link the various course topics. In contrast, minor guidance was needed by the treatment group.

With few exceptions (only 20% of students), the solution approach chosen by the control group to fulfill the project requirements was not the optimum solution, but rather one that was covered in earlier lectures leading to the project assignment. For instance, all students in the control group utilized only frequency domain analysis, despite the need to track specific variables in the time domain. For each of the variables, a new transfer function that relates the variable to the input was derived by the students. An easier and alternative solution, which was utilized by the majority of treatment group (70%), was to utilize the concept of state-space representation in their analysis, and revert to and from the frequency domain when needed.

It is worth noting that for both groups, DC motors were covered at the beginning of the course when modelling in frequency domain was discussed. The state-space concept was then discussed when modelling in time domain was introduced. The inability of the students in the control group to link the two chapters was evident by their choice of solution. Once the control group submitted their projects, the optimal solution was discussed with the students. They were informed that utilizing the state-space concept is far easier and more suitable to tracking state variables.

As mentioned earlier, the project of the control group was to study and analyze a third-order power generating system. On the final exam for the control group, students were asked to find the state space representation of the second-order power generating system shown in Fig. 3. The system shown in Fig. 3 is similar to that given earlier in the project shown in Fig. 1, except that the inductor on the generator side was eliminated and replaced by a wire.

Out of the fifteen students, only one student successfully answered the question. Three students attempted to answer the question, but only managed to solve less than thirty percent of the question. Their approach relied on frequency domain analysis. The remaining eleven students did not attempt to solve the problem. Apart from the student who answered the question correctly, all students had the propensity to solve the problem in the frequency domain. Since they knew it would have taken them a long time to reach the answer, they skipped the question and focused on completing the other exam questions.

On the other hand, on the midterm exam for the treatment group, a question was asked that required linking various concepts taught in different chapters. Students were given a second-order RLC circuit, and the graph of the step response of the circuit, which are shown in Fig. 4a and fig 4b respectively. The students were asked to determine the value of the inductor and the capacitor that would result in the given step response, for a specific resistor.

To answer the question successfully, students had to derive the transfer function of the system, and determine which portion of the transfer function is responsible for which characteristic in the given step response. Lastly, they had to relate the step response of the system to both the capacitor and the inductor parameters. Out of the ten students in the treatment group, five students solved more than eighty percent of the question. Four out of the remaining five students solved more than fifty percent of the question correctly, and were able to navigate back and forth between time and frequency domains. Only one student could not manage to link the topics and left the question blank.

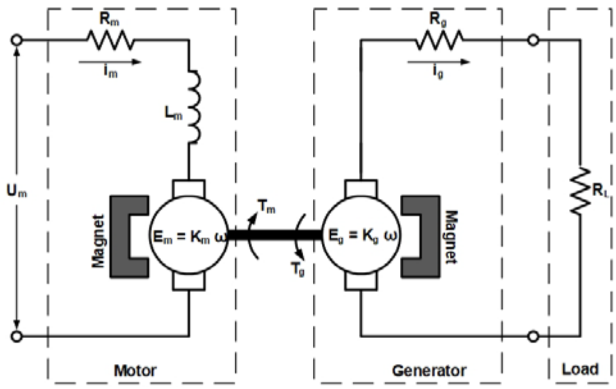
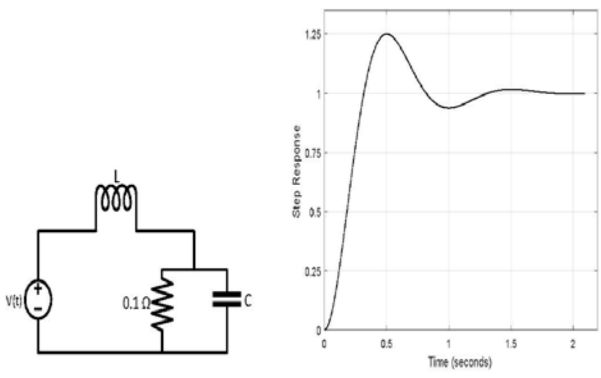


Fig. 3. Final exam question for control group.



(a) RLC Circuit. (b) Step Response.

Fig. 4. Midterm exam question for treatment group.

Throughout the semester, students from treatment group enquired about the possibility of solving problems from one chapter via the concepts of another chapter. They were keen on figuring out how to model any system in both frequency and time domains, and identifying the domain that is more suitable for the analysis at hand. In contrast, students from the control group struggled in linking the various chapter topics, and always tended to drift back to cookbook-type solutions.

It was also observed that the overwhelming focus of the control group was to solve a problem using the most direct approach that comes to mind. For instance, the concepts of stability and steady state errors were introduced to the students subsequently in the course. Students were informed that identifying steady state errors for an unstable system is a moot point. Nevertheless, when asked to find the steady state errors of a given system, the majority of the students in the control group failed to check the stability of the system first. Their ability to relate concepts of system stability and steady state errors was limited.

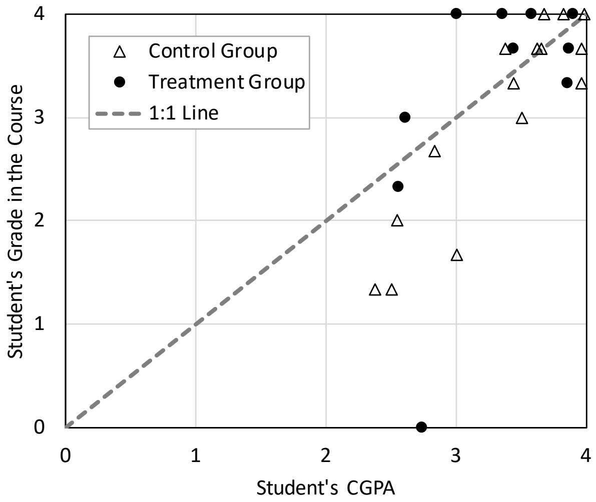


Fig. 5. Comparison between the students' performance in the course and their overall CGPA.

IV. Discussion

In addition to the qualitative assessment by the instructor, based on direct interaction with the students, a comparison is made between the student grades in the course and each student's cumulative grade point average (CGPA). This serves as an aggregated indicator of the level of attainment of the course learning outcomes which, when compared to the corresponding student's CGPA, provides information on knowledge acquisition and development in the course. The results plotted in Fig. 5 confirm the hypothesis that the treatment group performed better in the course. Out of nine students who passed the course, six earned a grade in the course higher than their CGPA. On the other hand, nine students out of fifteen in the control group performed below expectations in the course. These numbers mirror the findings reported in the previous section regarding the students' performance in the project and in exams.

Despite the fact that the average CGPA of the control group was slightly higher than that of the treatment group (3.35 vs 3.29), the treatment group performed better in the course. The improvement is attributed to the treatment group's ability to integrate their knowledge throughout the course, as evidenced by their problem solving skills.

Additional indicators of the effectiveness of the integrative learning approach were obtained from the end-of-semester instructor survey by the students. Seven specific questions in the evaluation, which are pertinent to this study, were extracted in an effort to assess the students' perception of changes in course delivery methods. The data presented in Table II indicates that the control group rated the professor's overall teaching skills, his ability to explain the material, his choice of assignment, and his ability to engage the students, higher than the treatment group. These traits, addressed through questions 1 to 4, do not specifically relate to the emphasis the professor placed on integrative learning, but rather to common best practices in conventional teaching settings. Conversely, questions 6 and 7 in the survey directly addressed issues at the

TABLE II. End-of-Semester Instructor Survey Scores

Questions	Control Group			Treatment Group		
	Instr	Dept	Univ	**Instr**	Dept	Univ
1. The instructor's overall teaching was excellent	**4.77**	4.03	4.39	**4.43**	4.16	4.30
2. The instructor explained the concepts and course material clearly	**4.77**	4.11	4.43	**4.55**	4.27	4.32
3. The instructor chose assignments that were appropriate for this course	**4.85**	4.17	4.48	**4.71**	4.21	4.35
4. The instructor encouraged student participation	**4.58**	4.17	4.41	**4.43**	4.19	4.30
5.The instructor answered student questions effectively	**4.69**	4.14	4.43	**4.71**	4.28	4.34
6. The instructor emphasized connections among course topics	**4.38**	4.23	4.41	**4.57**	4.38	4.33
7. The instructor was able to relate course content to what is happening in the world today	**3.85**	4.11	4.42	**4.14**	4.21	4.33

Note: *Scores for the Instructor represent the average for each group. On a scale* 1 *to* 5, *with* "1" *denotes strong disagreement and* "5" *denotes* core of integrative learning, namely the instructor's emphasis on connecting different course topics, and ability to relate the course content to the real world. The treatment group recognized the professor's emphasis on connections between the course topics, as well as his ability to relate the course material to the real world, better than the control group. This implies an understanding of, and appreciation for, integrative learning by the students.

Although the instructor's teaching skills were generally well above the university average, the difficulty in relating complex theoretical concepts in a math intensive course, such as control systems, to real world applications posed a challenge. However, it is interesting to note that despite the fact that the control group perceived the instructor's teaching skills more favorably than the treatment group, the latter ended up performing much better in terms of attainment of learning outcomes and ability to solve problems using more than one method.

V. CONCLUSION

Integrative learning entails the development of awareness toward linkages among different topics within a course, across several courses, or across different disciplines. A study was presented where two groups of students received different treatments in relation to integrative learning throughout their third and fourth years of undergraduate electrical engineering studies. The results support the notion that integrative learning is a skill that can be acquired through frequent reference to relevant topics covered earlier, and by demonstrating to the students that there are multiple approaches to solving engineering problems, all of which are correct. The ability to explore a range of alternative approaches to a given problem enables the student to reach an efficient and elegant solution, and maximizes attainment of learning outcomes. While this study was focused on a single set of courses within an undergraduate electrical engineering curriculum, further expansion of the concept of integrative learning into a broader variety of engineering disciplines will lead to better quantification of its impact on the student's ability to solve complex problems.

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