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A Control System Design Approach to Improve the Attainability of Student Learning Outcomes in Engineering Technology Courses

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Abstract

This paper discusses using a control system approach to analyze the achievement of Student Learning Outcomes (SLOs) in a course. As it is known that the SLOs are used as a guide to assess student learning progress as they work through the course. The SLOs not only serve the purpose of directing the content and design of a unit of study, they form the basis of assessment and are also linked to the overall program educational objectives set by the academic program in the form of generic and/or discipline-specific graduate attributes. The process of achieving SLOs in a course or a research project can be viewed as a dynamic system. Just as in a dynamic system, the input is tracked well with feedbacks and controllers, it is conceptualized that the same idea can be applied in assessing student learning outcomes in a course. The proposed method is comprised of identifying the SLOs for the course stated in the course outline as macro-SLOs and then developing lower level micro-SLOs, which contribute to individual macro-SLOs. These macro-SLOs and micro-SLOs constitute the inner and outer loops respectively of a dynamic assessment system. Further, appropriate tracking of SLOs can be ensured by having inner and outer loop feedbacks with controllers in each loop. The input and output of this dynamic system are the target macro-SLOs and achieved macro-SLOs respectively. Tests, exams, assignments, presentations, projects and other methods to assess students are the sensors that provide measured feedbacks to generate error function. The controllers in both outer and inner loops are the interventions in the system. The results of a case study from an engineering technology course are presented in this paper to demonstrate this approach.

Introduction

A dynamic system is a system that displays a dynamic behavior. In order to track an input, a dynamic system changes its state from one stage to another. Its movement from one point in state-space to another can be accomplished in infinitely many ways. These features allow a system to be controlled. If a system needs to track an input, its output is measured and used as feedback to construct an error function. By the application of the controller, this error is reduced as close to zero as possible. The manner, in which the error is brought to near zero, dictates the response of the system. Some of the methods used in control system design aim at minimizing integral square, L_2 norm, H_∞ norm, etc. of the error [1]. One of the most common types of controllers is a Proportional-Derivative-Integral (PID) controller. This approach of control system design can be applied to any dynamic system.

The teaching-learning system that is composed of a body of students and instructors is truly a dynamic system. The average knowledge of the class is moved from lower to a higher level by instruction methods throughout a course normally carried out in one semester. The evaluation of test and assignment scores in terms of student learning outcomes (SLOs) is used as feedback to determine the control strategy. This system is, in fact, a time-varying system in the sense that the parameters constituting the ‘plant’ are the students and their capabilities keep changing during the course. Moreover, since each student needs to achieve the required SLOs, it is a Multi-Input-Multi-Output (MIMO) system as well. Since the learning curve of each student is different and nonlinear, it is also a nonlinear system. Thus, it is possible to apply a control system design approach to analyze this dynamic teaching-learning system and improve the attainability of SLOs by students with appropriate simplifications. Even though the learning process of the student body is continuous, the feedback is sampled at a discrete interval of time and the control efforts are also applied for a fixed duration and designated interval. A unique feature of this system is that there is no need to minimize the control effort, unlike all the mechanical systems where control effort is minimized to save energy. The instructor would like to give as much time as possible to students and bring to them an abundance of resources.

The literature review on improving student learning indicates that almost all the attempts made by instructors to train students and help them achieve target SLOs are towards applying some intervention techniques. This approach is analogous to how a controller performs. However, none of them have analyzed this process as a control system. This paper aims at using the control system design approach for analysis of the attainment of SLOs.

The remaining of the paper discusses (i) control system configuration (ii) development/identification of macro-SLOs and a set of micro-SLOs for every macro-SLO, (iii) feedback and controller as intervention techniques to reduce the gap in attaining SLO, and (iv) case study to present implementation results of the proposed approach in an engineering technology course. The future work is discussed at the end followed by a relevant conclusion.

Control System Configuration

In a typical control system design, an input is followed by the system when the output of the ‘plant’ is used as feedback and the controller brings the error to a minimum level as shown in Figure 1. In a MIMO system, there is an array of inputs and outputs and with the appropriate controller, each input is tracked with the specified limits. If, however, the system is decoupled, each input-output pair can be tracked separately.

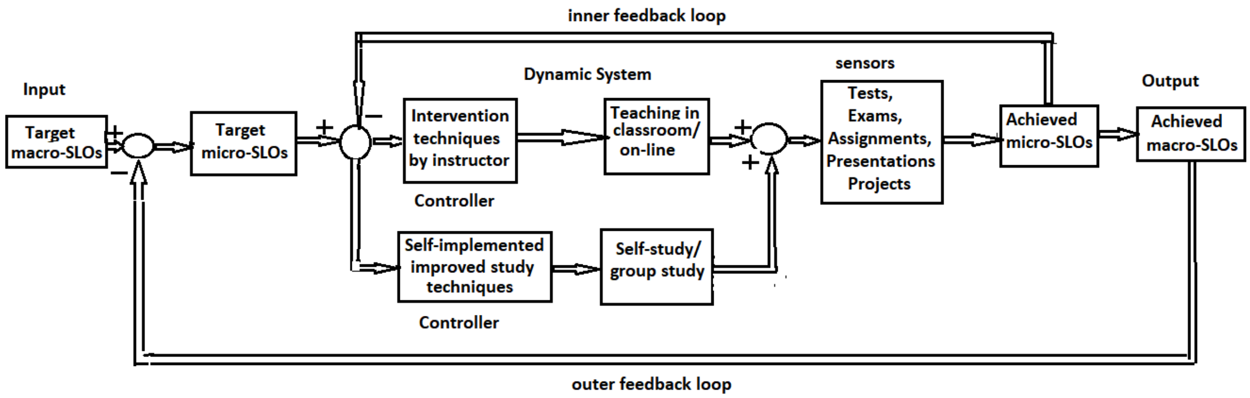


Figure 1. Control system configuration for achieving SLOs

In the case of a classroom teaching and learning system, we can treat the whole class as one Single-Input-Single-Output (SISO) system with average performance as a single output parameter. It is also possible to apply the same analysis for one individual student. The intervention techniques used by the instructor constitute the controller that drives the effort to minimize the error.

Thus, the proposed method of analysis is composed of identifying the SLOs for the course and then developing lower level micro-SLOs. These macro-SLOs and micro-SLOs constitute the inner and outer loops respectively of a dynamic assessment system as shown in Figure 1. Further, appropriate tracking of SLOs is ensured by having inner and outer loop feedbacks with controllers in each loop. The input and output of this dynamic system are the target macro-SLOs and achieved macro-SLOs respectively. Tests, examinations, assignments, presentations, projects and other methods to assess students are the sensors that provide measured feedbacks to generate error function. The controllers in both outer and inner loops are the interventions in this system.

One controller is driven by the course instructor while the other is driven by the students in the course. One of the requirements that must be met in a control system design is that the inner-loop is about 5 to 10 times faster than the outer-loop to have a quicker corrective action for micro-SLOs, which are implemented in the inner loop. Therefore, in this case, the outer-loop frequency would be once in a semester and the inner-loop frequency needs to be 5 times or more in one semester. This means that the course should have at least 5 evaluations carried out for micro-SLOs and these may be spaced out accordingly and evenly.

Identification of macro and micro SLOs

The macro and micro concepts for the curriculum process were present as early as 1970 [2]. In [2], two main purposes, one theoretical and other methodological are presented. The theoretical side describes the development of a model about the curriculum process concerning special frame-factors such as class-size and the system for ability grouping. The methodological side focuses on combining *"macro-approach"* and *"micro-approach"*.

In recent times, much attention is paid to study the learning ability of students and to develop numerous pedagogical intervention techniques that are implemented by instructors in the classroom. A comprehensive account of numerous techniques is available in various books, journals, and websites [3] – [5]. All these techniques point to the fact that the success of a course/program in a curriculum depends on how well the SLOs are defined for that course.

SLOs are like navigation tools such as a global positioning system (GPS). Once a destination is fed to GPS, the device guides the driver throughout the journey and the driver takes action to navigate correctly to the chosen destination. Similarly, learning outcomes are guiding tools that guide the students to the desired results of the planned course [6]. The aim of an academic course/program is indicated by SLOs as they give a clear idea of what can be achieved by joining a particular program. Whether it's a short course or a degree program, the learning outcomes should be listed and written down before the start of the course to know and to check whether the course is designed and conducted perfectly. To configure the system such that a control system design approach can be applied, it is necessary to identify these SLOs as target 'macro-SLOs'.

These macro-SLOs are defined by the accreditation board such as ABET-ETAC (Accreditation Board for Engineering and Technology - Engineering Technology Accreditation Commission) for Engineering and Technology discipline. According to the criteria for Accrediting Engineering Technology Programs, 2019 – 2020, these SLOs are specified as listed below [7]:

(i) an ability to apply knowledge, techniques, skills and modern tools of mathematics, science, engineering, and technology to solve broadly-defined engineering problems appropriate to the discipline;
(ii) an ability to design systems, components, or processes meeting specified needs for broadly-defined engineering problems appropriate to the discipline;
(iii) an ability to apply written, oral, and graphical communication in broadly-defined technical and non-technical environments; and an ability to identify and use appropriate technical literature;
(iv) an ability to conduct standard tests, measurements, and experiments and to analyze and interpret the results to improve processes; and
(v) an ability to function effectively as a member as well as a leader on technical teams.

However, these 'macro-SLOs' are very broad as they need to be to cover a wide range of courses offered in an engineering technology curriculum. Hence, one can accurately track target SLOs when they are broken down into micro-SLOs. While the macro-SLOs are general, the micro-SLOs are more specific to the particular course. For example, to evaluate undergraduate research experiences, a self-reporting tool is developed by [8]. The authors in [8] split the main macro-SLO of 'Reading and Understanding Research Literature' into the following nine micro-SLOs:

RD1: Conducting searches for research literature related to your research project (this does NOT include programming or technical guidance unless directly from a peer-reviewed published article)
RD2: Reading research articles in the discipline (i.e., physics/chemistry)

RD3: Reading research articles in the relevant sub-discipline (i.e., particle physics/organic chemistry)
RD4: Identifying the theoretical purpose to why given methods or techniques are used in the literature
RD5: Interpreting and critiquing the results and findings presented in the literature
RD6: Identifying further information necessary to support research-related results in the literature
RD7: Interpreting visual representations of data (i.e., graphs, diagrams, and tables) provided in the research literature
RD8: Discussion of research literature within ‘informal’ group setting (i.e., research group or journal club)
RD9: Create written or oral summaries of a research article

Similarly, each macro-SLO defined by ABET can be subdivided into micro-SLOs as appropriate for the course. An example is presented in the case study section of this paper.

Feedback and Controller

In order to have feedback, the SLOs need to be evaluated. Therefore, the micro-SLOs, based on which macro-SLOs are evaluated, must be measurable. Various methods of evaluation as found suitable can be implemented such as tests (multiple-choice questions, essay type, fill-in-the-blank, matching, etc.), assignments, classroom activities in the form of discussions, concept mapping, any measurable effort to establish a productive classroom environment and use of active learning techniques and so forth.

Each test must have at least one question about each micro-SLO. If there are more questions for one micro-SLO, then an average for each is computed. These micro-SLOs provide feedback in the inner loop. The average feedback for each macro-SLO is then computed based on the average of micro-SLOs. Often, the test scores are looked at when submitting the grades at the end of the semester. In the control system design approach, the analysis of the score must be carried out after each test. The first set of data reveals the level of each student and the average level of the whole class. When the second set of data becomes available, slopes for SLOs (both micro and macro) are evaluated. The control efforts are determined depending on which micro-SLO requires a higher slope. If the slopes are within the acceptable range, the previously applied method is maintained otherwise more attention is paid to the lower ones. As mentioned above, the number of evaluations must be between 5 to 10 times in a semester. This would allow less aggressive intervention measures to be adopted by the instructors.

The two types of controllers as shown in Figure 1, are distinct as one is applied by the instructor while the other by students. These ‘self-implemented improved study techniques’ may be suggested by the instructor. The effectiveness of these techniques can be ascertained after the analysis of each test data. The feedback would also be available to the students to improvise their controllers.

Case Study and Results

At Elizabeth City State University (ECSU), the control system design approach was implemented in an ENGT-235 (Analog and Digital Circuits) course offered in the Engineering Technology program. The following macro-SLO (ABET) was selected for this course and micro-SLOs were specified as listed below:

macro-SLO:
S1: an ability to apply knowledge, techniques, skills, and modern tools of mathematics, science, engineering, and technology to solve broadly-defined engineering problems appropriate to the discipline.

micro-SLOs for S1:
S1-1: Knowledge of fundamental laws for resistive circuits
S1-2: Knowledge of fundamental laws for capacitive circuits
S1-3: Ability to find the equivalent resistance in a series and parallel circuits and also in a combined circuit
S1-4: Ability to find the equivalent capacitance in a series and parallel circuits and also in a combined circuit
S1-5: Ability to apply Thevenin's theorem
S1-6: Ability to calculate current in each branch of a circuit with a combination of voltage and current sources
S1-7: Basic knowledge of PN junction
S1-8: Understanding of diodes, types of diodes, half-wave and full-wave rectifier circuits
S1-9: Basic knowledge of NPN and PNP transistors
S1-10: Ability to analyze circuits with transistors

The first test was conducted both in the classroom and on the Blackboard Learning Management System. It revealed the basic knowledge of students. Based on the score, following three different strategies were implemented:

(i) More questions on Ohm's law, combining resistive and capacitive circuits were set in the next classroom exercise and assignments.
(ii) Three groups were constituted for classroom activities such that each group had high scorers
(iii) Extra office hours were allotted to assist low scorers.

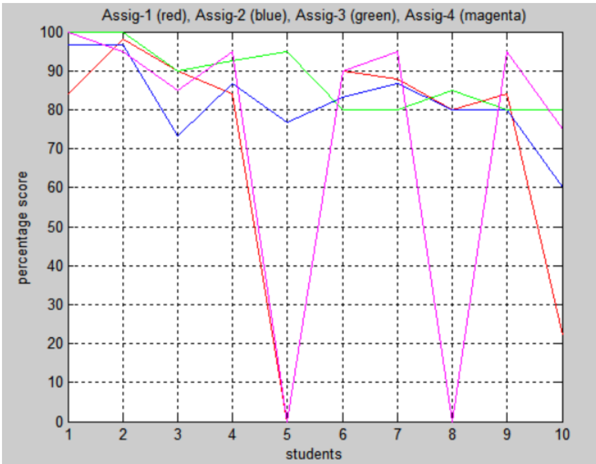
After a few more tests, when more difficult topics were being covered, more emphasis was placed on learning new materials such as PN junction, diodes, transistors, rectifier circuits, etc.

The new strategies that were introduced are:

(i) watching YouTube videos on the topics and opening discussions and setting questions on them
(ii) posting supplementary materials on Blackboard for help
(iii) classroom activities on identifying the application of formulas to problems

(iv) assisting in the exam at the cost of marks (1 point for choosing a correct formula, 2 for assistance in computation on a 5-point question)

The scores are presented in Figure 2 and Figure 3 below.



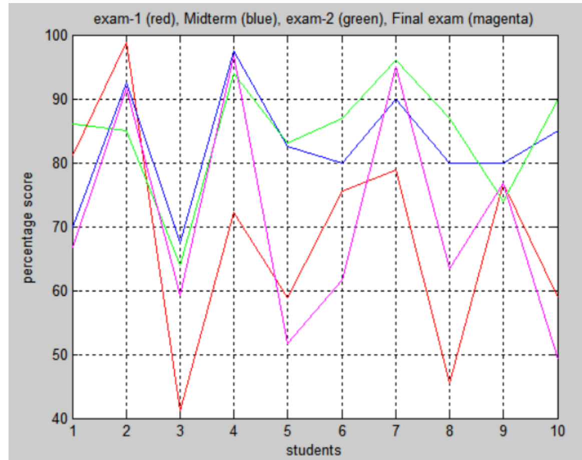


Figure-2 Scores of Assignments

Figure-3: Scores of Exam1, MT, Exam 2, and Final

The plots in Figure 2 and Figure 3 represents data for one macro-SLO chosen for this course. However, the details of micro-SLOs for each test and exam are presented in Tables 1 – 5. It should be noted that as different topics are covered in different tests and exams, not all have the same micro-SLOs. The distribution of micro-SLOs is shown below in Table 1.

Table 1. Distribution of micro-SLOs

	S1-1	**S1-2**	**S1-3**	**S1-4**	**S1-5**	**S1-6**	**S1-7**	**S1-8**	**S1-9**	**S1-10**
Exam-1	X	X	X							
Midterm	X	X	X	X	X					
Exam-2					X	X	X	X		
Final Exam			X					X	X	X

Tables 2 – 4 presents scores for three students (low, medium, and high) from the course. The average for the class is presented in Table 5.

Table 2. Scores achieved on micro-SLOs by Student 1

		Micro-SLO									
	macro-SLO	**S1-1**	**S1-2**	**S1-3**	**S1-4**	**S1-5**	**S1-6**	**S1-7**	**S1-8**	**S1-9**	**S1-10**
Exam 1	81	32	32	17							
Midterm	70	18	16	15	13	8					
Exam 2	86					30	22	22	12		
Final Exam	66			24					22	12	8

Table 3. Scores achieved on micro-SLOs by Student 2

		micro SLO									
	macro-SLO	**S1-1**	**S1-2**	**S1-3**	**S1-4**	**S1-5**	**S1-6**	**S1-7**	**S1-8**	**S1-9**	**S1-10**
Exam 1	41	19	14	8							
Midterm	67.5	17	15	12	11	12.5					
Exam 2	64					18	17	18	11		
Final Exam	59			20					14	15	10

Table 4. Scores achieved on micro-SLOs by Student 3

		micro SLO									
	macro-SLO	**S1-1**	**S1-2**	**S1-3**	**S1-4**	**S1-5**	**S1-6**	**S1-7**	**S1-8**	**S1-9**	**S1-10**
Exam 1	79	27	27	25							
Midterm	90	23	20	21	16	10					
Exam 2	96					29	24	27	16		
Final Exam	95			30					25	24	16

Table 5. Average scores achieved on micro-SLOs by the entire class

		micro SLO									
	macro-SLO	**S1-1**	**S1-2**	**S1-3**	**S1-4**	**S1-5**	**S1-6**	**S1-7**	**S1-8**	**S1-9**	**S1-10**
Exam 1	67	26	24.3	16.6							
Midterm	75.8	19.3	17	16	13.3	10					
Exam 2	82					25.6	21	22.3	13		
Final Exam	73.3			24.6					20.3	17	11.3

It can be observed that S1-3 is repeated three times apart from having them in assignments as it is crucial to the course. More emphasis was given to this and as a result, the average value increased in the final exam. The trend of micro-SLOs in the classroom activities and assignments indicates more closely the weekly progress and the personal interventions were made on an individual basis to improve them.

Direction for Future Work

In a study published in the Chronicle of Higher Education, the author grouped students into four categories namely, kangaroo, tortoise, hare, and frog [9]. A kangaroo type student waits until the end of the semester and then completes all assignments at the end. A tortoise type displays steady progress throughout while both hare and frog types make efforts sporadically. Thus, the control strategy would be tailor-made for each type. Therefore, in a large class, the scores should be analyzed to identify the categories of the student so that the appropriate control strategy could be adopted for each separately.

Further, for a thorough analysis of a dynamic system using a control system design approach, it is necessary to have a state-space representation of the system. The authors are engaged in developing a procedure to obtain such representation. Once that is available, the controllability of the system can be checked. That would be a valuable result. Based on that, if it is found uncontrollable then one can determine changes needed to make is controllable.

Conclusion

In this paper, an effort is made to analyze the attainability of SLOs using a control system design approach. The concept of feedback and controller is used to monitor and improve the attainability of these SLOs. Preliminary results from an engineering technology course were presented. It was demonstrated that the feedback obtained after each test is used effectively to formulate appropriate control strategies and implement them successfully to improve outcomes.

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