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Implementation of Active Cooperative Learning and Problem-based Learning in an Undergraduate Control Systems Course

Dr. Sanjay Jayaram, Saint Louis University, Parks College of Eng.

Dr. Sanjay Jayaram is an associate professor in the Aerospace and Mechanical Engineering Department of Saint Louis University. He obtained his Ph.D. in Mechanical Engineering from University of Central Florida in 2004. He teaches control systems/mechatronics, space systems engineering and astronautics related courses as well as engineering sciences courses. He has published several peer reviewed journal and conference papers in these areas. His research areas are space systems, robust fault tolerant control, nonlinear control, adaptive control, small spacecraft design, high performance spacecraft components, mechatronics, real-time health monitoring, and diagnostic methodology.

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Abstract

Recent years have shown a fundamental shift in undergraduate engineering education from lecture-based teaching methods to using more learner-centered approaches, specifically Active Cooperative Learning (ACL) and Problem-Based Learning (PBL) methodologies. ACL and PBL techniques have been identified by ABET as a pedagogical approach to promote learning outcomes. ACL and PBL techniques are widely known to be a motivating, student-centered strategy that foster student initiative and focuses the students on real-world, open-ended projects that can increase their motivation. Research from literature shows that ACL and PBL improves student knowledge and retention, motivation, problem-solving skills, and the ability to skillfully apply knowledge in new situations. Control Systems course is widely viewed by the undergraduate students in mechanical and aerospace engineering programs to be one of the hardest courses to understand the material.

Introduction

Active learning has several facets, including, collaborative learning, cooperative learning, problem-based learning, project-based learning, case-based learning, discovery learning, and just-in-time teaching. Active learning has been defined as any instructional method that engages students, whereas collaborative learning involves students working in small groups to reach a common goal [1, 2]. When student groups are more structured, the term “cooperative learning” has been used [3]. As opposed to traditional lecture-based instruction, active learning methods actively engage students in the educational process. These instructional methods invite students to become engaged, and therefore responsible for their own learning. Previous literature indicates that there is a strong consensus that active cooperative learning techniques as well as problem-based learning, and project-based learning are more effective than the lecture-based deductive approach [4, 11].

Collaborative learning refers to any and all of the instructional methods where students work together in small groups towards a common goal [5, 1]. It is viewed as encompassing all group-based instructional methods, including cooperative learning [1, 6, and 7]. The central element of collaborative learning is collaboration vs. individual work [1]. The model developed in [8] has five elements: mutual interdependence, individual accountability, face to face interaction, interpersonal and small group skills, and individual assessment of group functioning. Tools for assessment and evaluation of active and collaborative learning strategies for engineering courses are critical in this process [9, 10].

Problem-based learning (PBL) is a learning strategy where students are presented with an open-ended, ambiguous, preferably a real-world problem and work in teams to identify learning needs and develop a viable solution, with instructors acting as facilitators providing progressive disclosures rather than primary sources of information. PBL, by and large, is self-directed learning that helps develop positive student attitudes, foster a deeper approach to learning, and helps students retain knowledge longer than traditional instruction. Implementation of PBL technique in various levels of engineering courses is not a novel practice [12, 13, and 14]. Literature has found that PBL increased students learning skills, including problem-solving skill, literature searching skill, collaboration skill, and critical thinking skill – skills deemed critical of lifelong learning [15, 16, 17, 18, and 19].

Faculty and student perception of undergraduate control systems course varies widely. Control Systems course, by nature, mainly focuses on theoretical and abstract subjects. Even though the subject material has significant implications and applications in real world, it is very challenging for an instructor to attract and keep our students' interest when teaching it. At the same time, students see an overwhelming amount of mathematical theory and have difficult time connecting them to real life applications. This becomes even more challenging to aerospace and mechanical engineering students since they are unaccustomed to thinking of dynamic systems as input/output systems that can be chained together. Despite the importance of the subject, it has been considered as "dry and abstract" by students. Active cooperative learning techniques, including PBL is viewed as an effective pedagogy to teach and support student learning in control systems engineering. Examples of experiences with PBL in control systems are found in papers [20, 21, 22 and 23].

This paper addresses the implementation of ACL and PBL methodologies in the undergraduate control systems course in the Aerospace and Mechanical Engineering program at our university. These techniques were implemented during Fall 2012 and Spring 2013 semesters. The paper will provide details of various ACL and PBL techniques that were implemented. The paper will also present the approach used taking into account aspects like problem definition, progressive disclosure of problem requirements, timeline, lectures, student assessment, student evaluation, and student experience.

Benefits of ACL and PBL

Benefits of implementing ACL and PBL techniques in engineering curriculum to students is very well documented in previous studies and several papers previously presented in this conference. It will be beneficial to outline some of those advantages here:

- Provides opportunity to critical thinking, creativity and innovation in solving the problem
- Greater student-faculty and student-student interaction
- Facilitates positive interdependence and individual accountability
- Opportunities to connect the content and apply in real life examples
- Better team work and communication skills
- Higher level of achievement with deeper understanding of subject matter
- Recognition and appreciation for lifelong learning

Active Collaborative Techniques Implemented

The introductory control systems course is taken by the mechanical engineering students typically in the first semester of their senior year and by aerospace engineering students typically in their second semester of junior year. During the Fall 2012 semester, several ACL techniques were implemented in the course. This section describes those techniques and examples used to implement them:

a. Video Challenge: Student teams (3-4 students in each team) are given the task of developing a three minute video as a challenge. The video should be totally visual with no narration. This activity gives opportunity to students to work and collaborate in teams and gives them **autonomy** to create and present their own ideas. These videos are reviewed in one fifty-minute class period. The course material (theory and practice) is co-created by the students and the faculty.
Since the control systems class consists of both aerospace and mechanical engineering students, the video challenge was to develop the video that describes the history of control systems development on a particular concept, example, cruise control in automobiles, UAV control etc.

b. Quiz Bowl: This is a team activity (3-4 students in each team). This activity is utilized to reinforce the fundamental concepts of the subject material in each chapter. The activity is competitive, fun-based learning technique that gives autonomy to students.

How does it work?

- Each team prepare 10 $50.00 bills (their own design, Figure 1)
- Each team prepares two cards during each scheduled quiz, each with a question and answer and team name/number (the questions are sent to faculty in advance)
- On the day of quiz, all cards are collected by faculty and placed in a bowl
- Faculty randomly picks a card
- Faculty informs the question is from which team, so that team members monitors which other team raises their hand first to answer the question
- Faculty asks the question
- Team which answers the question gets $50.00 from the team that prepared the question or the team answering wrong will give $50.00 to the team that prepared the question
- At the end of the semester, each team counts the bills that they got from other teams. Team with highest number of bills earned wins the competition.

Figure 1: Quiz Bowl Currency

c. Jigsaw Poster Activity: Jigsaw is a cooperative learning strategy that enables each student of a “home” group to specialize in one aspect of a problem. Students meet with members from other groups who are assigned the same aspect, and after mastering the material, return to the “home” group and teach the material to their group members. Each student’s part is essential for the completion and full understanding of the proposed solution. This technique engages all students and is very effective. In the end, the teams were required to develop a poster.

Implementation:

- Form Cooperative (Home) Groups

  Give each member one part of the assignment.

- Break into Expert Groups

  All Home Group members leave the Home Group and form an Expert Group consisting of all the members in the class with the same part of the assignment. The goal of the Expert Group is:

  - Learn and become an expert on their part of the assignment.
  - Plan how to teach the material to the other members of their Home Group.

Jigsaw Exercise:

One of the three major US automobile companies has given a task to the student teams to research and recommend the future direction. Rank or pick your top two choices of the following automobile safety control system technologies to be pursued for further research and development. Prepare a poster in defense of your selection.

a. Electronic Stability Control (ESC) system
b. Automatic Distance Control (ADC) system
c. Lane Departure Warning (LDW) system
d. Integrated Brake Control (IBC) system

Benefits of Jigsaw Activity:

- Instead of having material presented to them, students learn the material through research, teaching other team members and discussion, thus fostering deeper understanding.
- Students become “subject matter experts” in one particular area of the problem and share/educate other team members.
- During a jigsaw, students speak the language of the discipline and become more fluent in the use of discipline-based terminology.
- Students have autonomy in learning material and have the opportunity for meaningful contribution.
- Jigsaw encourages cooperation and active learning and promotes valuing all students' contributions.

- Opportunity for the group to present and defend their findings in an “elevator pitch” scenario.

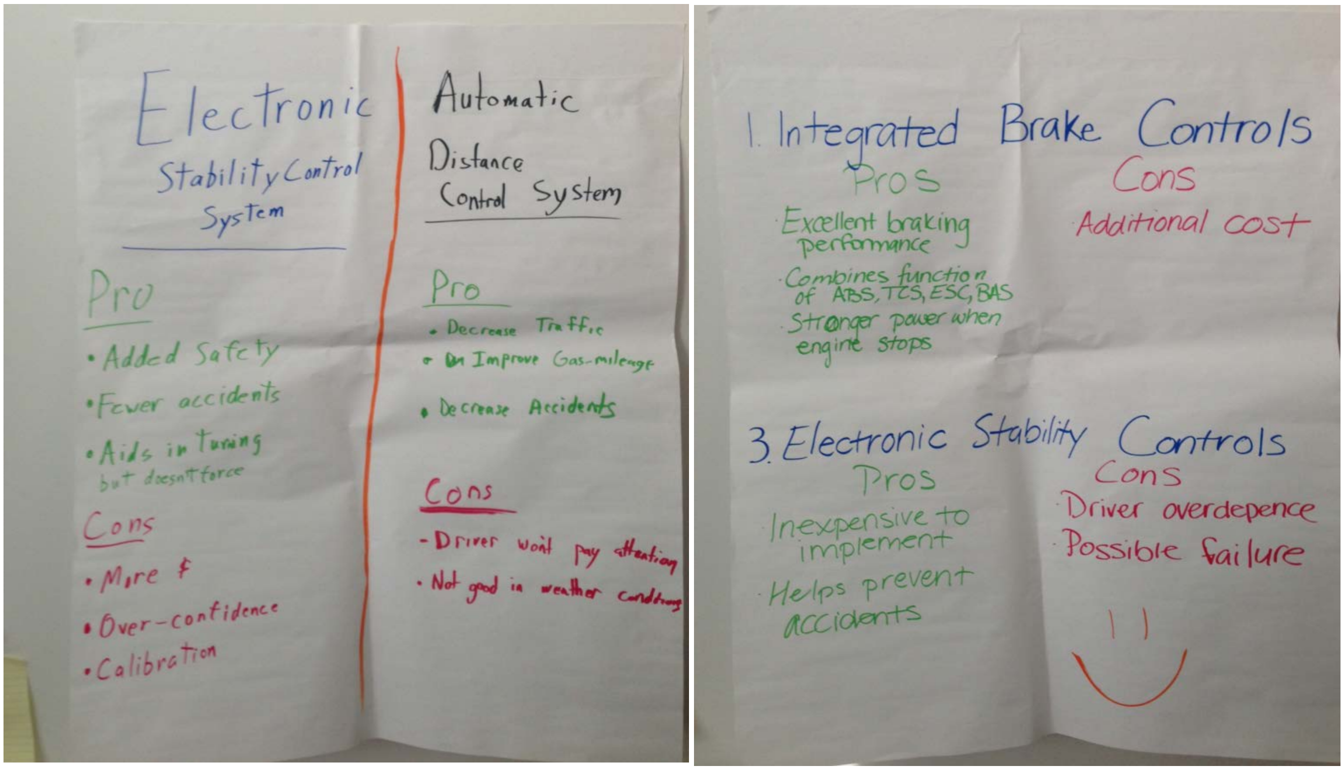

Figure 2: Student Generated Jigsaw Posters

Problem Based Learning (PBL) Activity

During the Fall 2012 semester, an aircraft landing gear controller design was used as problem-based learning activity. The students were grouped into 4 members per team. Some of the common features of PBL that were implemented during this activity are listed below:

- Learning is initiated by a problem
- Problems are based on complex, sometimes real-world situations (and usually open-ended)
- All information needed to solve problem is not given initially (i.e., ill-defined)
- Ambiguity!!
- Students identify, find, and use appropriate resources (this and previous point are usually “staged” or “progressively disclosed”)
- Students work in permanent groups
- Learning is active, integrated, cumulative, and connected

Figure (3) shows the generalized PBL process

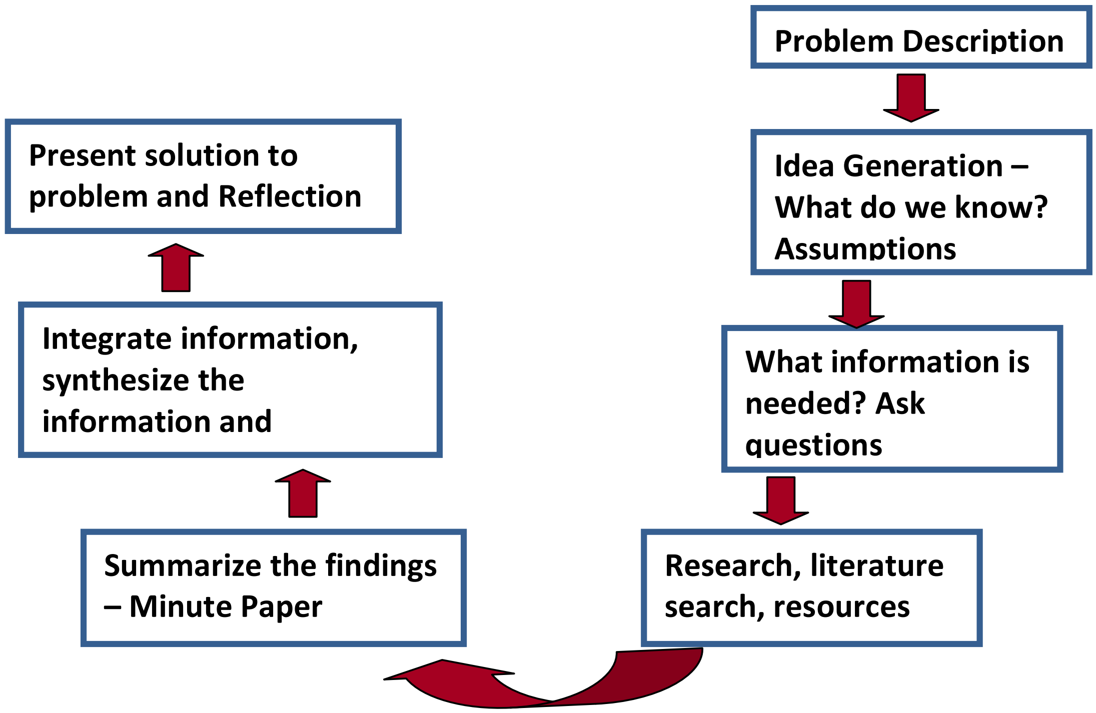

Figure 3: Generalized PBL Process

PBL Exercise

In introductory control system courses, it is possible to design and run a single problem through-out the course including many concepts in different modules of the course. Once the PBL problem is designed it is also important to identify categories of engineering knowledge which can be addressed in problem solving process. The steps involved in solving the problem are outlined below:

Step 1: Pose a real application control design problem
Step 2: Develop a physical model of the system to be controlled.
Step 3: Mathematical modeling (Newton's Law or Lagrange's principles, linearization, using Laplace transformation or State Space methods)
Step 4: Performance Analysis of the system to the controlled (performance criteria/specifications, stability analysis – Routh Hurwitz and root locus)
Step 5: Define desired performance characteristics that needs to be achieved
Step 6: Identify controller structure and design the controller.
Step 7: Analyze the performance of the system with controller using MATLAB based simulation
Step 8: Evaluate the design and tweak the controller gains to achieve desired performance.

Figure (4) shows steps in control system design problem.

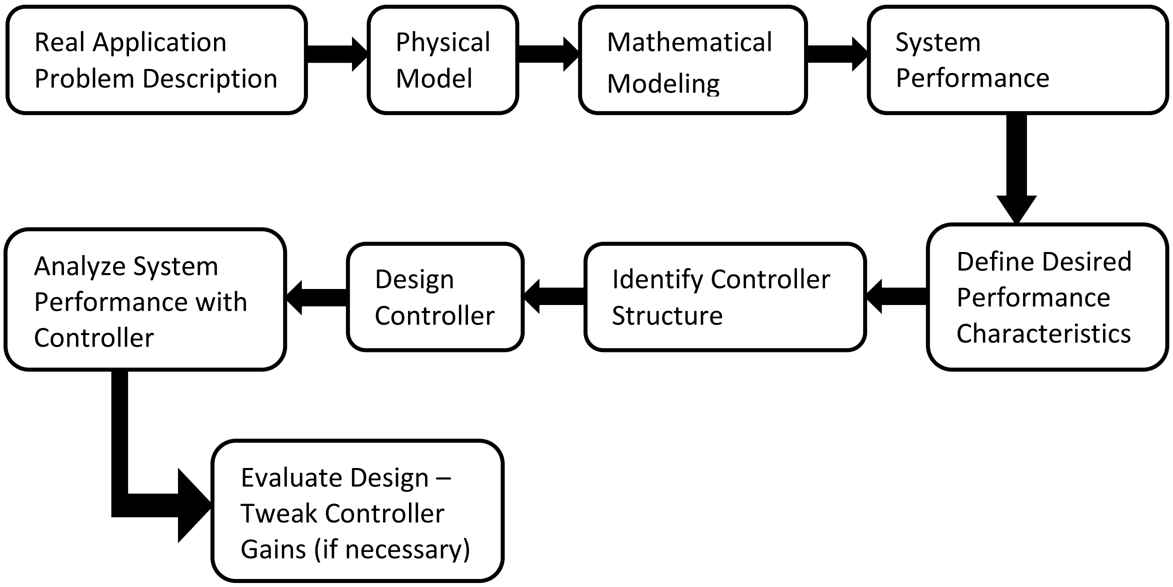

Figure 4: Steps in Control Systems Design Problem Solving

Please see Appendix A for the complete description of the PBL exercise.

Team Formation

The class had students from aerospace engineering, mechanical engineering and mechanical engineering. The student were not asked to form their own teams, rather the teams were formed in such a way so that each team had at least one student from different disciplines. The teams were formed based on their birth month (quite random) so that they had to work with team mates whom they would not know previously. Both the ACL activities and PBL project teams were same.

Student Assessment and Feedback

A survey was designed to assess the impact of the PBL and ACL activities on the student's knowledge about control systems theory and design. A total of 15 students in the class responded to the questionnaire survey. The following paragraphs provide a detailed description of assessment results. Table 1 show the survey questions for ACL techniques and Table 2 show the survey questions for PBL techniques.

Table 1: Active-Cooperative Learning Activities - JIGSAW Poster and Quiz Bowl:On a scale of 1 -5, with the scale designated as 5 for strongly agree (SA), 4 agree (A), 3 for Neutral (N), 2 for disagree (D), and 1 for strongly disagree (SD), please rate the following questions:

		SA	A	N	D	SD
Q1	The activity helped you to conduct contemporary research and gather information					
Q2	The activity helped you to be more active in the learning process and helped to promote critical thinking in comparison with lectures, for example					
Q3	The activity is a good method for promoting understanding of Control Systems applications in real world					
Q4	The activity helped you to discuss and share information with other team members					
Q5	The activity helped you to and cooperate with other team members					
Q6	The Quiz Bowl activity reinforced the understanding of the fundamental concepts and improved self-assessment					

Table 2: Project Based Learning:
On a scale of 1 -5, with the scale designated as 5 for strongly agree (SA), 4 agree (A), 3 for Neutral (N), 2 for disagree (D), and 1 for strongly disagree (SD), please rate the following questions:

		SA	A	N	D	SD
Q1	Project-Based Learning (PBL) activity related to real-world application					
Q2	Project-Based Learning (PBL) is effective in engaging students in learning					
Q3	Project-Based Learning (PBL) is effective in stimulating critical thinking					
Q4	Project-Based Learning (PBL) is effective in increasing Student collaboration					
Q5	Project-Based Learning (PBL) is effective in increasing the quality of education					

The survey results show that the preliminary results and the informal feedback from the students are encouraging (Figures 5 and 6). In the forthcoming semester, it is planned to move beyond simple student surveys to more objective assessment of student achievements. With a total of 15 students responding to the survey, the standard deviation for ACL survey is 0.224 and the standard deviation for PBL survey is 0.122.

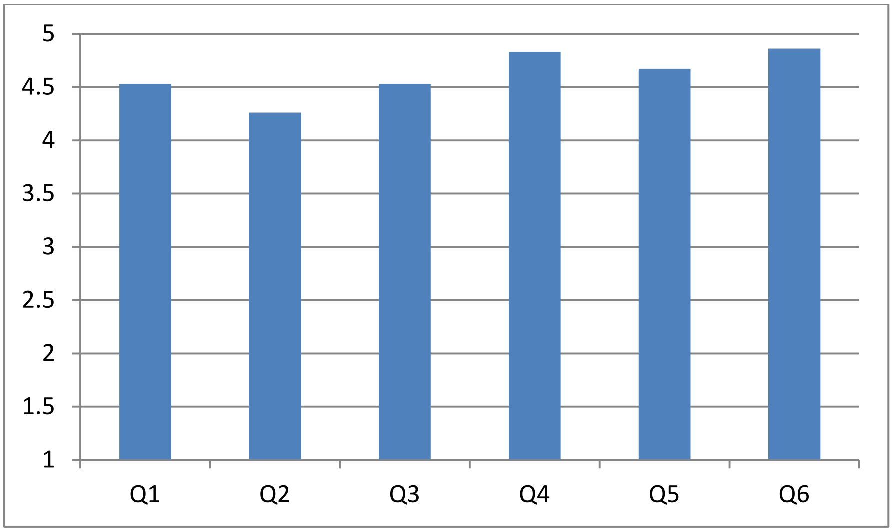

Figure 5: Survey Results for Active-Cooperative Learning Activities - JIGSAW Poster and Quiz Bowl

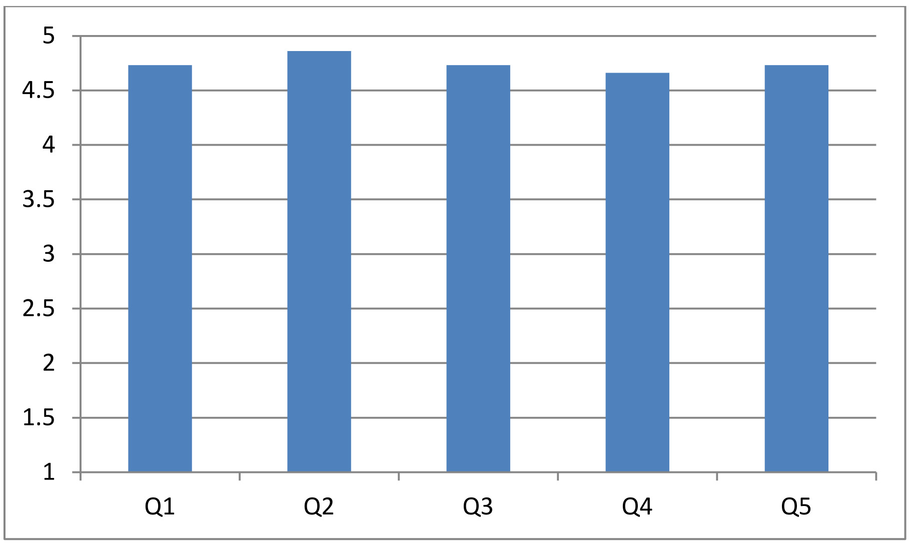

Figure 6: Survey Results for Project Based Learning

The initial student feedback (in Fall 2012) suggested that the use of ACL and PBL approach was advantageous to students in retaining the fundamental concepts and address a real life problem. The author of this paper has taught this course in a traditional manner for over ten years and is very well aware of the feedback received from students. A more direct comparison to a traditional course was not done at that time, but such an assessment is planned in the Spring 2013 semester. Since that assessment will be done at the end of Spring 2013 semester, it is not possible to include the results of that assessment in the paper, but the author will present the findings during the conference presentation. The following points illustrate some of the commonalities:

- The same course content is covered with no significant change in the "flow" of the content compared to traditional approach. The course schedule has minor modifications to include the ACL activities and PBL updates spread over the entire semester.
- The PBL work is performed outside the classroom with "minute paper" updates every two weeks. All the ACL activities are performed during the class. (each ACL activity typically taking half class time or one full class time, depending on the activity).

The student survey questions were prepared to get a direct feedback from the students. The survey was answered by students (not self-reported).

Based on years of experience teaching this course, the author has found enough evidence from student interactions that ACL/PBL methods has significantly improved the course material retention and has provided students with better understanding of the importance of control systems engineering in real, practical applications. Through this paper, the author intends to provide potential ACL activities that can be readily implemented by other faculty members and also a template of how a PBL activity could be generated.

Students Comments/Feedback

Some of the comments and feedback received from students regarding implementation of ACL and PBL techniques in Fall 2012 are shown below:

ACL Comments
"I liked the quizbowl, it was fun and overall a pretty good way of reinforcement"
"Learning actual applications of control systems in the active learning poster project"
"Having to make poster in a really short period of time was difficult"
"The quizbowl was good because of the competitive spirit it involved"
"The Jigsaw poster was fun and informative. It was an effective way to learn applications of modern control systems in a relaxed approach"

PBL Comments
"The PBL project gave us the opportunity to utilize the materials learnt in the class"
"I think it would be valuable to connect the theory and practice to actual control hardware/components"
"There were sometimes no enough information or the instructions were a little ambiguous"

Summary/Conclusions

This paper has provided a detailed description of the project-based active and cooperative learning approach that was developed for an introductory undergraduate linear control systems course. Student perception of their implementation of the ACL/PBL techniques is encouraging and instructor observations confirm better implementation of these techniques than in semesters where these techniques were not used. Student comments and survey results indicates these techniques were extremely helpful in terms of student learning and faculty implementation with the greatest self-reported student gains occurring when both ACL and PBL techniques were used in the course. Overall, students had positive opinion of implementing the ACL and PBL techniques.

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Appendix A

ESCI 430 – ANALYSIS AND CONTROL OF LINEAR SYSTEMS – PROBLEM BASED LEARNING ASSIGNMENT – FALL 2012

Problem Title: Landing Gear Controller Design for SAE Aircraft

Student Learning Objective(s)

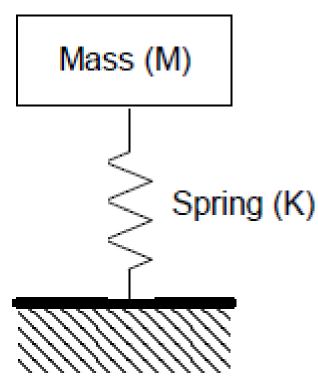
1: Reinforce the concept of mathematical modeling of physical systems, transfer functions, system performance analysis and system stability.
2: Design and simulation-based verification of a linear controller based on the given performance criteria.
3: Determine design parameters considering the societal context (i.e customer requirements, available resources, etc.)

Brief Abstract/Description of Problem

The SAE Aircraft Design Team has designed and built a 55 pound aircraft for the competition. The designed landing gear has a linear spring (to absorb impact of landing) of K = 500 lb/ft. During flight testing and landing of the aircraft, it was noticed that the aircraft experiences lot of oscillations and takes a lot of time to dissipate. The aircraft has two landing gears (one each below the wings). For simplicity, the aircraft with landing gear can be modeled as a "mass-spring" system. The student group has asked you to provide the controller design and numerical simulation analysis. For the team to proceed further, discuss among yourself and see:

a. What further details are required? Any assumptions?
b. Brainstorm ideas!
c. Progressive disclosure on the design constraints will be provided later

End Deliverable: Controller Design and MATLAB Simulation. Clearly specify all necessary assumptions.



STAGES:

Stage 1: Problem formulation, analyze the need and brainstorm ideas – research findings and idea generation report (**1 Page, minute report**)

Stage 2: Model and compute the equations of motion for the system. Express the equations in proper format (Laplace or State Space) for analysis. Do the performance analysis and discuss the behavior of the system (including stability using root locus technique). (**1 Page, minute report**)

Stage 3: Based on the performance criteria to be achieved (provided later in progressive disclosure), determine what type of controller is suitable for achieving performance goals. (**no page limit**)

Stage 4: Design the controller gains and perform MATLAB simulation. Compare the controlled and uncontrolled system performance and discuss the results. (**no page limit**)