Destabilizing Classical Controls Learning: Problems, Projects, and Virtual Labs

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Motivation for Change

The reviewed literature lays out multiple underlying issues that motivate a change to the pedagogical techniques employed in control engineering education. Many of these issues are common across engineering education, while others are specific to the unique discipline of control engineering. Heck (1999) summarizes trends in control education that partially drive this change. These trends include the introduction of modern control techniques in the undergraduate classroom, the use of information technology in education, reintegrating practical control topics over rigorous mathematical based theory, and broadening undergraduate control study to include other disciplines. Bernstein (1999) is one author who focuses on emphasizing the practical aspects of control. He argues, and this author agrees, that control engineering “tends to be the least tangible of all subjects in the engineering curriculum.” Bernstein then goes on to advocate teaching the experiential aspects of control over the conceptual. Other authors argue that the current control engineering curriculum produces graduates who do not work well on teams and are poor practical problem solvers (Paja, Scarpetta & Mejia, 2005; Bissell, 1999). This same criticism is leveled against all engineering graduates by Mills and Treagust (2003). Those authors state that this failure is due to the lecture oriented classroom that has predominated engineering education since the 1950s.

Proposed Solutions

The solutions to the aforementioned issues that I found in the literature roughly fall into the following categories:

1. Problem-Based Learning (PBL)
2. Project-Based Learning (PJBL)
3. Virtual Laboratories
4. Other interactive/experiential learning, typically assisted by Information Technology

Problem-based learning (PBL), as described in (Perrenet, Bouhuijs & Smits 2000; McKeachie, 2006) is an experiential learning pedagogical approach where students are presented with a problem first instead of the facts and knowledge needed to solve the problem. The approach assumes that students will be motivated to self-learn the necessary knowledge and skills
needed to solve the problem. In some models of PBL, students meet in small groups during multiple phases (Perrenet et al. 2000). The solution proposed by Paja et al. (2005) blends both PBL and the virtual laboratory. In this case, the authors use a remote laboratory concept, where students can access physical lab equipment 24/7 over the Internet. While the remote lab concept itself is not novel, the theoretical concepts map that the authors propose is a useful tool to assist students in acquiring necessary knowledge. The proposed system also operates in such a fashion as to be closely related to the guided design steps outlined by McKeachie (2006).

Mills and Treagust (2003) also discuss the implementation and applicability of PBL to engineering education in general. They found that problem-based learning may not be the best solution, partially due to the hierarchal knowledge structure in engineering and ill defined problems.

Project-based learning (PJBL) is also discussed in the literature as a promising pedagogical technique for control engineering education specifically (O’Mahony, 2008) and other engineering education in general (Mills & Treagust, 2003; Lei et al. 2012). PJBL is more loosely defined in the literature than PBL. A good working definition is provided by Mills and Treagust (2003) as any “unit of work” that is based on self-direction and collaboration. Perrenet el al. (2000) provides a list of differences between PBL and PJBL. Some noted differences are that PJBL tasks typically take longer, require more subject-matter courses, and require more self-direction. The most noted difference may be the relationship to knowledge. As Perrenet et al. (2000) state “[PJBL] is more directed to the application of knowledge, whereas PBL is more directed to the acquisition of knowledge.”

O’Mahony (2008) provides a detailed account of transitioning a traditional lecture plus lab control engineering course to a project based course. The motivation for changing the course was to increase student motivation, to emphasize and reinforce the controller design process, and to provide deeper understanding through less prescriptive experiments. The projects are undertaken in cooperative teams and modified lectures provide technical knowledge to support the projects.

Laboratory experiments in control engineering are typically used to reinforce or introduce practical control issues. However, as Pereira, Paladini, and Schaf (2012) note, reproducing real controls equipment is expensive and can be dangerous. Their proposed solution is to utilize both remote and simulated labs. By integrating these labs into virtual labs and virtual learning environments (VLEs) similar to Second Life, the authors argue that active learning and cooperative learning can be achieved in these VLEs. Other research in remote labs has promoted the cost savings and possible pooling of resources across universities as the main benefit, while noting that current content management systems lack adequate support for this model.

Another approach to changing control education that is discussed in literature is to promote experiential learning using new information technology tools (Bissell, 1999; Dorato, 1999; Dormido, Dormido-Canto, Dormido R, Sanchez & Duro 2005). Dormido et al. (2005) highlight the necessity of visualization in control design and promote a simulation suite that they claim
can lead to intuitive understanding of control engineering. Bissell (1999) argues that most implementation of information technology in the controls classroom has been used to simply replace hand calculations. He also states that computer tools should be more central to a modified curriculum.

Bissel (1999) also advocates other radical changes to control education that don’t fit into any of the four categories above. His most radical idea is that the current controls curriculum should be “inverted”. Modern control techniques that are more practical and intuitive should be taught in an introductory course, while the rigorous mathematical theory and classical design should be saved for upper level coursework. There is no literature to suggest that this radical redesign has been implemented by any program.

**Recommendations**

Based on the literature reviewed, the following recommendations should be followed to enhance undergraduate controls education

- Implement project-based learning (PJBL) to some degree, whether as an entire course or as a single “module” or “block” within a course.
- When implementing project-based learning, be prepared to reduce technical subject matter content.
- Be upfront with students about the implementation of PJBL; prepare them for a slightly higher workload and spend class time discussing teamwork.
- Take time to step back from theoretical foundations in order to illustrate and discuss practical control design issues.
- Explore implementing more post-1950’s control theory, such as rule-based and fuzzy controllers.
- If implementing PJBL, explore alternate student evaluations such as peer and self evaluations.
- Provide as much hands on design and laboratory experience as possible. Implement remote or virtual labs to augment physical labs with many different plants to study.
- Fully implement Computer Aided Design (CAD) tools as a central focus of the curriculum, not as replacement for hand calculations.

In conclusion, it is possible to reinvent the classical controls classroom using project-based learning, virtual laboratories, and information technology tools. The literature concerning control education contains both theoretical techniques and practical implementation examples that can be used to transition a traditional course from lecture-based to a student-centric, active learning environment.

**References**


**Annotated Readings**


This article by a respected and widely read control engineer challenges educators to reevaluate the control engineering curriculum. The author provides a summary of the typical control engineering curriculum in the United Kingdom and then argues that this curriculum is too detached from real-world engineering problems due to its reliance on mathematics, theory, and reductionist modeling based on the natural sciences. Bissell also critiques the failure of integrating information technology into control engineering education. He states that information technology has simply been used to automate old exercises in the old curriculum, instead of designing modified curriculum around the changing information
technology tools. Finally, the article lays out a strategy for change with a central tenet of “inverting” the current control curriculum.


The author lays out 21 different suggestions for emphasizing the practical aspects of control engineering. He offers these suggestions as a path for transitioning control education from conceptual to experiential. His suggestions include dynamic analogies, bringing dimensions back into a typically dimensionless field, and system identification. The author then goes on to emphasize the importance of measurement, the basic physics of control, and the importance of balancing the abstract control theory with concrete applications.


The authors take an in depth approach to the “remote” controls laboratory. The paper includes highly technical discussion of the integration between the remote hardware and learning management/content management systems. The main goals of the system are to reduce costs associated with providing multiple control engineering examples, provide cross-disciplinary learning, and allow as many people as possible to contribute lab-based learning objects.


This short (two page) article discusses control education as a service course for other standard engineering disciplines (such as electrical engineering or mechanical engineering) and its focus on classical control in the analog domain. The article highlights the fact that engineering education in the U.S. is shorter and typically less technically focused than other countries. The author argues that introductory control courses should include digital control, hands on design, post 1950’s theory, and more computer control and simulation exposure.


In this paper the authors present a suite of information technology tools that allow the control engineering student to directly apply control visualization. These tools are focused on the classical controls student, and are extremely similar to the SISOtool package that is now built in to MATLAB. The authors state that the effects of controllers visualized using this system can lead to an intuitive understanding of the underlying mathematical basis.


In this paper the authors introduce a Rube Goldberg project for teaching first year electrical engineering to both electrical engineers and other engineering majors. The course has traditional lecture format classes for introducing technical topics, one hour tutorial classes, and four pre-project laboratories that introduce students to the equipment and components necessary to complete the project. The authors found that over half of the students were enthusiastic about the project; however many expressed that the project was time consuming and the workload was heavy.

This often cited paper analyzes the effectiveness of both problem-based and project-based learning as alternatives to the “chalk and talk” method. The authors assert that the lecture oriented format of education that has been the model used in engineering education since the 1950’s produces graduates that have good fundamental engineering knowledge; however, these graduates fail at applying this knowledge in practice. The authors examine both individual courses and programs that have implemented either project or problem based learning. They found that problem-based learning may not be the best solution, partially due to the hierarchal knowledge structure in engineering and ill defined problems. On the other hand, project-based learning produces motivated students who demonstrate better teamwork and communication skills, at the expense of engineering fundamental knowledge. The authors conclude that a mixed-mode approach of traditional courses with project-based components appears to be the best pedagogical approach. The project-based components should increase as a student progresses through the curriculum. The authors advocate that this model should spread as widely as possible through engineering curriculum.


The author describes his experiences with transitioning a 4th year Controls Engineering Course, which is the second out of two control courses that students take, from a traditional lecture plus lab format into a project-based format. The project takes central focus within the course, and lectures are modified as needed to support the project. The motivation for changing the course was to increase student motivation, to emphasize and reinforce the controller design process, and to provide deeper understanding through less prescriptive experiments. The paper discusses both the cooperative learning aspect, to include assessment and the possibility of “firing” team members, and the technical content. It is interesting to note, that in order to transition the course, over half of the technical content was removed.


The authors of this paper take a modern approach to designing control engineering labs. The paper examines the advantages and disadvantages of physical and remote labs, but then goes one step further than other research when examining virtual labs. Typically, virtual labs are treated as simple computer simulations. However, the authors found that both simulated and remote labs led to “trial and error” techniques instead of the desired sound application of engineering principles. They found that by integrating remote and virtual labs into virtual learning environments (VLE) similar to Second Life, they both increased student motivation and performance.


In this paper the authors describe the motivation for and development of a web-based system for implementing problem-based learning in a classical controls context. The motivation for the pedagogical technique is to prepare students to function on multidisciplinary teams that solve real-world problems. The motivation for the virtual, web-based system is to integrate the information technology environment while controlling costs. The virtual system is comprised of four basic tools – theoretical concepts,
mathematical analysis, simulation, and experimentation. The analysis and simulation tools described are not unique from other, widely available and used tools other than the web-based access and possible lower cost. However, the theoretical concepts tool described is unique and provides a concept map approach similar to guided design. The experimentation tool that the authors have built is also unique in that it allows students’ access to a hardware based multi-experiment system without the overhead and time constraints of a typical physical lab.