AC 2011-798: PRINCIPLES AND STRATEGIES FOR DEVELOPING AND IMPLEMENTING AN INTERDISCIPLINARY UNDERGRADUATE CURRICULUM

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Principles and Strategies for Developing and Implementing an Interdisciplinary Undergraduate Curriculum

Abstract

Traditional undergraduate engineering disciplines, due to their focus on single disciplines, cannot meet the growing need for engineers skilled in multiscale design: they educate engineers to handle systems issues or component issues, but not both. Furthermore, many interdisciplinary programs in engineering are more focused on developing knowledge and skills in multiple component-level domains (e.g., mechatronics focuses on developing component level knowledge in electrical, mechanical, and computer domains) than in component-level and systems-level areas.

These observations serve as the basis for the Technology Leaders Program (TLP), a transportable interdisciplinary program being developed at the University of the Blue Ridge and Central Community College. The TLP is designed to develop in students 1) a deep understanding of the need for interdisciplinary knowledge that is at both component- and systems-levels, 2) disciplinary grounding in a component-level domain (electrical and computer engineering) and a systems-level area (systems engineering), 3) integration skills whereby students can design integrated systems of electrical and computer components, and 4) critical awareness of the need for this combination of knowledge and the opportunities and limitations for its application. Development and implementation of the TLP began in 2008 with the first class of students entering the program as sophomores in 2009.

The purpose of this paper is to report on the key principles used in structuring and implementing the Technology Leaders Program. These principles focus on ensuring benefits to students in the program and developing a clear sense of identity for the TLP. In addition, the process of transporting the TLP to other institutions is described, with a focus on transporting core elements of the TLP (not necessarily the entire TLP) and on improving the TLP through the process of transporting it to other schools.

Introduction

The primary goal of the Technology Leader Program (TLP) is to prepare students for a world where both component-level and system-level knowledge are necessary to be leaders in technological fields. In particular, the TLP is an interdisciplinary undergraduate program integrating computer, electrical, and systems engineering[1,2].

Starting formally in August 2008, with students first enrolling in August 2009, the TLP's initial goals focused on developing a sustainable program at the University of the Blue Ridge and Central Community College. During its third year, goals have shifted from development of the program to its transfer to other institutions.

In this paper, we detail key factors contributing to the successful implementation of the program at the University of the Blue Ridge as part of a general review of the status of the TLP. In addition, we report on the strategy for spreading core elements of the TLP to other institutions. First, however, the structure of the TLP is outlined.

The Technology Leaders Program

To fulfill its goal of educating students with both rigorous systems integration and detailed electrical and computer component design skills, the structure of the TLP is built around a model of interdisciplinarity developed by Boix-Mansilla[3]. The essence of the Boix-Mansilla model is captured in four dimensions:

1. **Purpose**: students must understand the reason why multiple disciplines are necessary to solve a given problem
2. **Disciplinary Grounding**: students must have fundamental knowledge from all of the disciplines needed
3. **Integration**: students must know how to integrate the different worldviews, approaches, and tools used by the different disciplines
4. **Critical Awareness**: students must be able to reflect on the appropriateness and utility of taking an interdisciplinary approach for a given problem.

Students apply for the TLP at the University of the Blue Ridge at the end of their first year and, if accepted, are in the program from their sophomore through senior years. These students major in one of three majors: computer, electrical, or systems engineering. Because the electrical and computer engineering programs are intertwined, it is helpful to think of the TLP consisting of two main groups of students: systems (SYS) majors and electrical/computer (ECE) majors.

In the sophomore year, the main focus is on **disciplinary grounding**. Students take their normal introductory courses of their major and also take the introductory courses from the other major. For example, systems engineering students take two electrical engineering courses (circuits and digital logic design) and electrical and computer engineering students take two systems engineering courses (systems methodology and information systems) in addition to their required major courses. In the junior-year, **disciplinary grounding** in a student's major continues while disciplinary grounding in the other major (ECE for SYS majors, SYS for ECE majors) tapers off.

The tapering is due to an increased focus on **integration** in the third year. The focus of the third year is two TLP classes (one each term) in which teams work to design and build actual systems. Finally, in the fourth year, students continue to concentrate on **integration** while completing capstone projects designed specifically for TLP teams.

Purpose/need and **critical reflection** are incorporated into the TLP curricula through the TLP Learning Community. The TLP Learning Community meets every two weeks for one hour with goals of developing a sense of belonging among the students, educating students about the engineering field, strengthening leadership skills among students, and helping students learn skills for getting jobs and internships. All students in the program – sophomores through seniors – participate in the learning community together.

An overview of the TLP structure is shown in Figure 1.

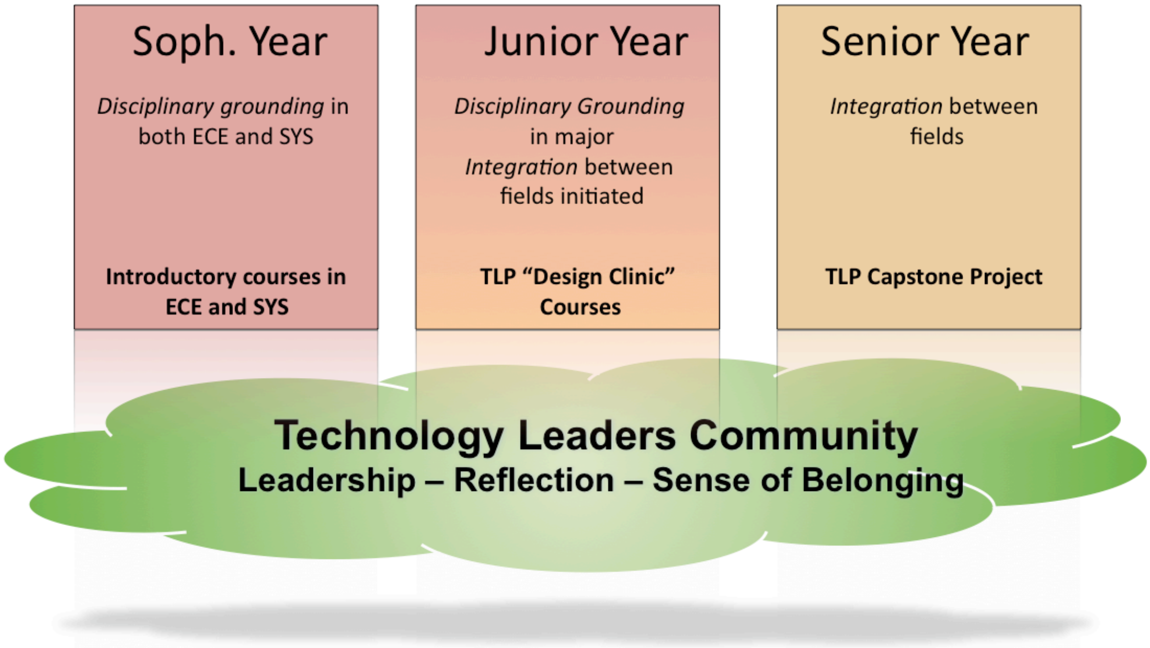

Figure 1 Overview of the Technology Leaders Program

We first accepted students in Fall 2009 – the application process for this class is detailed in a prior paper[2]. Thirteen students are part of this first TLP class.

The second group of students began the TLP in Fall 2010. Fifty-two students applied for the program during the previous spring. We accepted twenty-seven and turned away twenty-five. Criteria for acceptance focused most strongly on a student essay, in which we evaluated the degree to which their motivation for wanting to be in the TLP matched with the objectives of the TLP. GPA was a factor, but not a significant one.

Of the twenty-seven students whom we invited to join the TLP, twenty-four accepted. Of those twenty-four who accepted the invitation to join the TLP, two eventually left the University of the Blue Ridge and two others decided to not stay in the TLP.

A demographic breakdown of the students in the TLP is shown in Table 1.

Table 1 Demographics of TLP Students

	Class starting Term **Fall 2009** 13 Students	 **Fall 2010** 20 students	**Entire TLP** 33 students
MAJOR			
Computer science or computer engineering	3 (23%)	6 (30%)	9 (27%)
Electrical engineering	4 (31%)	7 (35%)	11 (33%)
Systems Engineering	6 (46%)	7 (35%)	13 (39%)
GENDER			
Female	5 (38%)	6 (30%)	11 (33%)
Male	8(62%)	14 (70%)	22 (67%)
ETHNICITY			
Asian	5 (38%)	4 (20 %)	9 (27%)
Black / African American	3 (23%)	3 (15 %)	6 (18%)
Hispanic	1 (8%)	1 (5 %)	2 (6%)
White	4 (31%)	12 (60%)	16 (48%)

Critical Components of the Technology Leaders Program

The success of a program such as the TLP hinges on A) developing a program structure that will attract and retain students, B) implementing said program structure, and C) adapting the program structure as you learn more about what works and what does not. In this section, we report on the first two dimensions. In the following section, we report on the third dimension.

Attracting and Retaining Students in the Technology Leaders Program

Two principles have guided the TLP in its efforts to attract and retain students. First, students clearly must benefit from the program and perceive that they are benefitting it. These benefits could be tangible (e.g., internship offers to TLP students) or less tangible (e.g., being part of a smaller community at a large school). The second principle is that students need to identify as participants or members of the TLP. Both of these principles stem from the goal to make the TLP more than a collection of courses and a line on a resume or transcript. Many minors in engineering schools are just that – and a student minoring, for instance, in mechanical engineering has little idea as to who the other students minoring in mechanical engineering are and has little chance of developing a mechanical engineering disciplinary identity. To differentiate the TLP from programs such as minors, we saw the need to structure the TLP such that students developed a disciplinary identity distinct from other students in their major, could clearly see the boundary of who was and was not in the program, and have ownership in shaping the future of the TLP.

Principle #1: Students should be benefiting from the program and should perceive that they are benefitting from it.

Twenty-two of the thirty-three TLP students completed a survey in August 2010. Results from one question on that survey are reported here. That question was "What attracted you to the TLP? Please be as specific as possible."

Of the twenty-two students, 6 were in the August 2009 TLP class and 16 were in the August 2010 class. Ten were majoring in systems engineering, eight in electrical engineering, and four in computer engineering. Seventeen were male and five were female. The overall breakdown is shown in Table 2. Unfortunately, no women in computer engineering responded.

Table 2 Number of Respondents to Survey By Sub-Group

	Electrical Eng.		**Computer Eng.**		**Systems Eng.**	
	Male	Female	Male	Female	Male	Female
August 2009 Class	1	1	1	0	2	1
August 2010 Class	5	1	3	0	5	2

Open-coding was used to analyze the responses. Five high-level codes emerged from the coding process. These five showed that students were attracted to the TLP because they wanted to:

1. develop interdisciplinary skills
2. improve chances of finding a job
3. build stronger relationships with peers and professors
4. learn through hands-on, authentic experiences, and
5. improve their leadership skills

The last two codes were seen sparingly and only among the students just starting in the TLP (August 2010 class). Building stronger relationships, the third code, was cited often by students in the 2010 class but by none in the 2009 class. Developing interdisciplinary skills and improving chances of finding a job, however, were widespread among the students in both years, all three majors, and both genders. Encouragingly, many of the students directly referred to, in their own words, a desire to develop a perspective and skills that address both systems integration and technical component design. That is, most students did not just say "I want to have interdisciplinary skills," but instead focused on the top-down/bottom-up pairing of systems engineering and electrical and computer engineering that is at the core of the TLP.

In summary, the strongest theme that emerged from the responses is that students are attracted to the TLP because they want to diversify their skillset so that it is more interdisciplinary as a means to get better internships and jobs. These are two of the central goals around which the TLP was structured; the students' desires are good matches to the program.

Principle #2: Students need to identify with being in the Technology Leaders Program.

Dozens of academic programs exist at the University of the Blue Ridge for engineering students. Minors in nearly all of core engineering majors (e.g., chemical engineering minor, mechanical engineering minor, systems engineering minor, etc.), specialty minors (e.g., an engineering business minor, a society and technology minor), honors programs, and various other programs are all available for students.

One key structural difference between the TLP and nearly all of the other programs is the utilization of a learning community as a means for students to build a sense of identity with the program and to help shape the program. A student can be rather anonymous in most other programs – taking some courses and filling out a form is all that is required. With the TLP, on the other hand, key roles for the learning community are to make a student know that they are a member of the TLP, that other TLP members know that they are a member of the TLP, and that they are expected to be active in shaping the TLP program itself. The learning community, by meeting regularly and including all TLP students and several TLP faculty, promotes a sense of TLP identity and provides opportunities for students to build relationships with others in the program. A representative set of topics and activities for several TLP learning community meetings is shown in Table 3.

Table 3 Representative Learning Community Topics and Activities

Sensors in the Wild	student teams ran around campus finding as many sensors as they could in 20 minutes, emailing photos back to a central email account to review with everyone in the TLP
TLP Industry speakers	topics have included how electrical, computer, and systems engineering are used to created cutting technologies seen on shows like CSI and to develop collision avoidance systems for airplanes
Leadership/Teamwork	topics have included conflict management activities, the impact of Myers-Brigg styles on leadership, and business case study role playing
TLP Logo Design	students designed several logos and are led the process of selecting a final design

Implementing A Critical Component of the Technology Leaders Program: The New Junior-year Design Courses

The two junior-year TLP courses are the only new courses created specifically for the TLP and are critical components for several reasons. First, they are key places for TLP students to reach key TLP learning objectives, such as being able to design and build from both a systems, top-level perspective and a detailed, component-level perspective.

Second, they are the first place where TLP students work specifically on integrating skills from the different disciplines. Third, it is a course that is exclusively for TLP students, which further differentiates the TLP from other minors/programs and helps students identify more strongly with the TLP.

The first semester junior-year course (first taught in Fall 2010) was designed to focus on a single motivating real-world problem: elevator design. Students worked in three teams and started with the systems-focused questions "What are the objectives of elevator systems?." Reduce wait time? Reduce average transit time? Increase the number of people moved per hour? Reduce the cost of the system? Etc.

Teams worked through using systems concepts such as simulations of different configurations and algorithms… paired with building a scaled-down physical prototype of the system with sensors, motors, and related electrical components. Each team could choose how to proceed, resulting in three different approaches to the project. One team relied most heavily on software and algorithmic improvements. Another team relied more heavily on gaining significant additional information from additional sensors and information inputs with which the system could make decisions about where to send elevator cars. The third team used far fewer off-the-shelf components than the other two in their physical prototype and, as a result, explored the comparative advantages and disadvantages of custom versus off-the-shelf parts.

The **most significant observation** about the course concerns how to best structure an interdisciplinary course focused on developing additional disciplinary grounding AND integration of knowledge from the disciplines. The intent in these courses is for electrical (EE), computer (CpE) and systems (SYS) engineering students to learn new material about each discipline AND to begin learning about when and how to integrate these disciplines to respond to real world problems. Teams were formed with both ECE and SYS students on each team and were allowed to structure their teams as they desired. The result **was that students from each major gravitated to work related to their major.**

EE students worked directly with EE parts of the project such as the physical prototype – building circuits, ordering and integrating sensors and motors, etc. Computer engineering and computer science students worked mainly with software/coding. SYS students worked mainly on integration (objectives, measurable requirements, optimization, etc.) and simulation.

This result, while not surprising in hindsight, was not our vision for the course… a vision that included all majors working more closely together and not only contributing work from their discipline, but also integrating their work in a "more than additive" way. We were aiming for a course where all students would gain new disciplinary knowledge from all of the disciplines… not just their own. In short, what occurred was more multidisciplinary while what was envisioned was more interdisciplinary.

A significant challenge is to make the junior-year courses rich in EE, CpE, and SYS while also providing integration opportunities that are not silo-ed. Embedding more disciplinary content for all students is a challenge that must be solved by the faculty leading the program and teaching the courses. Shifting to more interdisciplinary integration opportunities (instead of multidisciplinary) will require changes by the faculty… but it also will require critical awareness (refer to Boix-Mansilla interdisciplinary model) by the students about the relative advantages of working in a multidisciplinary team versus an interdisciplinary team. Faculty also will need to provide the structure and space in which this reflection can occur.

Additional data collection about the first junior-year course is planned by the evaluation team. We hope this additional evaluation work will show us what individual students learned from the experience and the course shaped the TLP students' perceptions of multiscale design.

Transporting the Technology Leaders Program to Other Institutions

With many of the major components of the TLP implemented at the University of the Blue Ridge, more effort has shifted towards transporting the program to other institutions. Transporting the program has been a significant goal since the program's initial conception. Early activities towards this goal revolved around establishing relationships. For instance, we created an advisory board consisting of representatives from potential institutions to where the TLP could be transported. Since then, efforts have been directed towards increasing faculty and departmental awareness of the TLP at other institutions. The next shift will concentrate on identifying and executing specific opportunities to transport the program to other schools.

Two notable strategies are being taken in getting the program started at other schools. First, we are focusing more on transporting the core elements of the TLP than on the entire TLP program. Second, we aim to transport the TLP to other institutions where barriers we have faced would not exist. In other words, not just transporting to replicate the program, but transporting to improve it.

Transporting the Core

As outlined in this paper, there are several core elements of the TLP that have made it successful at the University of the Blue Ridge. These elements include the following:

- a primary goal is to **integrate top-down approaches** (e.g., system engineering, system design) with **bottom-up approaches** (e.g., domain specific component design/analysis skills)
- a **learning community** is a central feature of the TLP
- like the Learning Factory at Penn State, the TLP focuses on integrating **hands-on design and implementation skills** into an engineering education
- the TLP is built around the **Boix-Mansilla model of interdisciplinary understanding**, with disciplinary grounding and critical awareness being important in addition to integration
- the TLP is **built largely with existing courses**

By seeking to transport core elements, instead of making this "all or nothing," there are more possible institutions to which to transport the TLP(e.g., the institution does not have to have a systems engineering department) and we can better fit in relevant components at another institution (e.g., another school may already have a system design-focused curriculum in electrical engineering… and the learning community could be the primary element from the TLP transported to that school).

Transporting to Improve

Transporting to improve starts with identifying areas where the program has not succeeded as well and reasons for such challenges. As an example, a less-successful area for the TLP is the development of the program at Central Community College. Reasons for the challenges experienced at Central Community College are difficult to isolate, but possible reasons include:

- the distance between Central Community College and the University of the Blue Ridge
- the lack of an electrical or systems engineering program Central Community College
- departure of original P.I. at Central Community College early in the development of the TLP

A community college, Southern Community College, was found that addressed the first two possible reasons for challenges at Central Community College. Southern Community College already had an electrical engineering program and was located roughly 4 miles from the University of the Blue Ridge.

The partnership with Southern Community College started in late Fall 2010, but the outlook for the collaboration is positive. Students at Southern Community College have already expressed interest in joining the TLP and have attended TLP Learning Community meetings at the University of the Blue Ridge. The first class of students at Southern Community College accepted into the TLP should start electrical engineering courses in Fall 2011.

Conclusions

Midway through the third year since the Technology Leaders Program was created, two principles have emerged as being important to the program's success at the University of the Blue Ridge. First, students need to know they are benefitting from the TLP. While we have more work to do to better capture students' perceptions about benefits of the TLP, their perceptions of benefits align well with TLP goals. Secondly, it is important that students identify with the program and build relationships with others in the program. The learning community is the central structural part of the TLP that promotes students identifying with the TLP, with the junior-year TLP-only class also promoting a sense of identity.

The junior-year courses have provided a significant challenge in that we aimed for students to both further their disciplinary grounding in both ECE and SYS and also begin to integrate these disciplines on real-world, hands-on projects. In the Fall 2010 junior-year course, the opportunities for interdisciplinary integration tended to dissolve into multidisciplinary collaboration. In addition, the focus on integration and real-world projects made it difficult to further the students' disciplinary grounding in ECE and SYS. Plans are in place to adjust the Spring 2011 junior-year course to address both of these challenges faced in the Fall 2010 junior-year course.

Finally, our focus has shifted significantly towards transporting the TLP to other institutions. Two strategies are being employed in this process. First, we are focusing on transporting core elements of the TLP moreso than trying to transport the entire TLP to other schools. This is aimed at increasing the possible institutions at which the TLP could be a good match. The second strategy is to transport the TLP to schools that provide an opportunity to improve the TLP, not just replicate parts of it. This second strategy is proving successful in transporting the TLP to Southern Community College, where many of the challenges faced at Central Community College do not exist.

References

1. Bailey, R., B. Choo, H. Rowan-Kenyon, A. Swan and M. Shoffner. 2009. "Educating engineers for multiscale systems design in a global economy: the Technology Leaders Program " *American Society for Engineering Education Annual Conference*, Austin, TX, June 14-17.
2. Bailey, R., H. Rowan-Kenyon, A. Swan, M. Shoffner and A. Coso. 2010. "Implementing an interdisciplinary engineering program – recruiting students, building courses, developing a community." *American Society for Engineering Education Annual Conference*, Louisville, KY, June 20-23.
3. Boix Mansilla, V. and E. Dawes Duraising. 2007. "Targeted assessment of students' interdisciplinary work: an empirically grounded framework proposed " *Journal of Higher Education* **78**(2): 215-237.