Learning Streams: A Case Study in Curriculum Integration

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***Abstract* – During 2004-2005, the Departments of Electrical and Computer Engineering and Mechanical Engineering at Iowa State University in collaboration with educational colleagues in the Research Institute for Studies in Education piloted a new curricula model to improve student learning through vertical integration of educational activities using new program structures. We offered an experimental course sequence during Fall 2004 and Spring 2005, defined as a "learning stream." A learning stream is a basic element of a novel program structure designed specifically to vertically integrate subject matter across courses. A learning stream merges and re-organizes material to more effectively present and reinforce key objectives. Concepts are covered in a more cohesive and timely manner compared to traditional topical organizations, letting students see relationships between concepts. A learning stream emphasizes fundamentals through their application. In some cases, it provides a basis to introduce cross-disciplinary ideas. Students gain proficiency with higher dimensional problem-solving from a conceptual and disciplinary perspective rather than a single subject. The design of a curriculum using learning streams addresses one of the most important questions in engineering education, that is, how to achieve balance between the fundamentals and applications, between theory and practice. In this paper, we describe the learning stream model, a pilot offering, its evaluation, and lessons learned.**

Index Terms – Curriculum integration, Learning Stream, undergraduate program, vertical integration

INTRODUCTION

The Department of Electrical and Computer Engineering in collaboration with the Department of Mechanical Engineering and educational colleagues are developing a new curricula model applicable to undergraduate engineering programs. The project is titled Vertical Integration of Computer, Electrical and Mechanical Engineering Education, or VIE, an acronym that suggests the word *vie*, particularly its meaning of *invite, challenge, strive, compete*. The goal of the project is to *invite* and *challenge* a number of constituencies to work together to improve student learning through integrated programs and experiences. The fundamental premise of the project is integration through community: integration of curricula, integration of research and teaching, and integration of interdisciplinary information. In this paper, we describe the **learning stream** model, a novel approach to vertically integrate educational activities using new program structures and organizational practices.

DEFINITION OF A LEARNING STREAM

A learning stream is a new basic curriculum element, or building-block. The idea of a stream is to integrate subject matter across traditional courses, and in some cases, across disciplines, so that engineering students become accustomed to higher-dimensioned problem-solving, from a disciplinary perspective rather than from a single subject. This involves the development of highly vertically integrated curricula, which enables and fosters the development of critical-thinking skills necessary to solve a problem. The design of a curriculum around learning streams has the effect of vertically integrating subject matter across courses. It addresses one of the most important questions in engineering education, that is, how to achieve balance between the fundamentals and applications, between theory and practice. With learning streams, we introduce fundamentals through their application. Whereas a "learning community" provides a horizontal foundation, a stream overlays a vertical arrangement incorporating many of the same pedagogical strengths, e.g., community, collaboration, learner centrality, retention, etc.

An illustration of a stream-based undergraduate program is shown in Figure 1. Figure 1 is an approximation based on nominal credits in an eight-semester program. For example, the first blue line represents a four-semester (long) stream taken during the freshmen-sophomore years. In traditional terms, it would be equivalent to four 3- or 4-credit courses. But structuring the program using streams is nontraditional and forces us to think, teach, and learn differently. Thus, the stream model represents a new organizational practice intended to meet the need for integration.

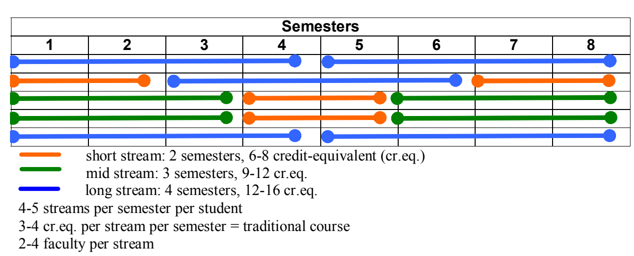

FIGURE 1: STREAM-BASED UNDERGRADUATE PROGRAM

Note that a learning stream (LS) is not simply a set of modules; that is, it involves more than taking a modular approach to course design. Similarly, it goes beyond being a collection of knowledge units that are defined in the body of knowledge of a discipline. It also should not be confused with an option in a program. The following characteristics of the learning stream model distinguish it from traditional approaches.

Problem-based Design. A set of units in a learning stream teaches skills, techniques, and tools needed to solve a problem, meet a goal or develop critical-thinking. The content of a stream is *not* defined by traditional course boundaries and topics. The stream bridges the "knowledge gap" that exists between basic knowledge (fundamentals) and applied knowledge by spanning traditional courses and levels in a program.

Faculty Collaboration. Faculty work closely together in specially coordinated, 2-4 person teams to ensure each stream meets its learning outcomes. Streams are cross-fertilized as faculty typically work on more than one stream in a given semester.

Sense of Community. The stream design promotes the notion of "membership" for both faculty and students.

Curricular Flexibility. A learning stream may be equivalent to 2-4 semester courses, ranging from 6-16 credits. Lower-level streams focus on freshmen-sophomore years; upper-level stream focus on the junior-senior years. Mixed streams across these levels forge key learning connections. Selection of streams partially determines a degree program.

Rigorous Program Assessment. Specific stream learning outcomes coordinate with course learning outcomes as well as map to program outcomes. A stream is formally reviewed for its relevance to the curriculum, support for program outcomes, etc.

A simple, disciplinary stream may be illustrated within a traditional program flowchart by connecting a sequence of related courses. For example, an engineering program may include an "engineering core" stream, such as a math LS. In electrical and computer engineering, there may be major streams (that distinguish EE, CPE degrees); and streams such as Digital Systems (including traditional courses such as digital logic, microcontrollers, and computer organization), Bioinformatics, Embedded Systems, Communication & Data Networking, Software Lifecycle, High-speed Systems, Nanosensors, Interactive Environments, etc. For example, a bioinformatics stream may include units on Computer Data Structures, Algorithms, and Applications in Biology and Bioinformatics, which cover basic data structures and algorithms as applicable to biological systems and bioinformatics. Such a stream may also include instruction in basic biology/chemistry and programming language constructs. In mechanical engineering, examples are Mechatronics Systems as one stream, and Thermodynamics Applications as another. The mechatronics stream is interdisciplinary, including EE subject matter on circuits, motors, and microcontrollers.

A learning stream curriculum model promotes the following educational principles and attributes:

Learning Community Benefits

- Support of and need for effective and efficient team-teaching
- Learner-centered instruction
- Conduit for interdisciplinary teaching and learning

Adaptable Structure

- Diverse faculty base (expertise, training, etc.)
- Linkage between research and curriculum
- Cyclic review and continuous improvement

Industry-based Design

- Emphasis on contemporary problems
- Vertical integration similar to industry
- Well-defined organization that fosters innovation and communication
- Application of problem-based learning

CURRICULUM INTEGRATION

Curriculum integration is described as the use of learning activities to build contextual connections between topics [1]. It enhances the ability of students to transfer knowledge to new situations, and improves retention and recall of material by making it relevant. It offers students a "bigger picture" view of the material. In a sense, it emphasizes the "big ideas," referred to by Wiggens and McTighe as the enduring or important understandings that we expect students to "get inside of" and "get inside of themselves" [10]. The primary design principle behind the learning stream model is curriculum integration.

Recently, a variety of efforts have focused on improving the integration of engineering education through problem solving and critical thinking [1-9,11]. For example, the Platform for Learning project uses a problem-based approach in which the traditional course structure is tied together within the context of single laboratory platform across courses [1]. It uses a common unifying object or experience to illustrate the inter-relationships and interdependencies of the classes.

Learning streams allow students to work as part of learning teams to see practical applications, observe engineering problems, and discover solutions with hands-on experience. Learning streams provide a framework for critical thinking.

PILOT LEARNING STREAM

We piloted a learning stream for computer engineering, replacing a traditional course sequence of CprE 210-211-305 over three semesters with the integrated stream sequence of CprE 281X-381X over two semesters during Fall 2004 and

Spring 2005. The "X" refers to an experimental course, which is Iowa State's convention for piloting new courses.

Traditional Course Sequence:

- CprE 210, Introduction to Digital Design (4 cr., 3-2)
- CprE 211, Introduction to Microncontrollers (4 cr., 3-2)
- CprE 305, Computer Organization and Design (4 cr., 3-2)

→ Learning Stream Sequence:

- CprE 281X, Digital Logic, Processors, and Programming I (4 cr.); CprE 282X, Lab (2 cr.)
- CprE 381X, Digital Logic, Processors, and Programming II (4 cr.); CprE 382X, Lab (2 cr.)

The CprE 210, 211, and 305 classes have a natural progression of learning that focuses on the building blocks of digital systems design and microprocessors. We transformed the subject matter of these courses into a "stream" to join it more fluidly, bringing it together in a learning experience that features "just-in-time" learning for students and also closes the knowledge gaps that can occur from disjointed courses and instructor styles. This pilot stream was team-taught by two professors who have closely worked together in designing the course content and lab content. The Research Institute for Studies in Education (RISE) at Iowa State has worked with instructors to evaluate the effectiveness of the model. Since both the traditional sequence and the stream sequence were offered, comparisons were made between the two approaches.

ASSESSMENT

RISE performed an external curriculum assessment for the learning stream that was implemented in Fall 2004 and Spring 2005 semesters. The evaluation was informed by ABET Criteria, focusing on Criterion 3 Program Outcomes, as well as other relevant criteria. The curricular assessment was focused by questions in the following five areas: accountability, effectiveness, impact, organizational context, and unanticipated outcomes. Assessment results included here are preliminary and incomplete because the activities were ongoing when this paper was written. For purposes of demonstrating the impact of the pilot project, results are focused on effectiveness and impact. Specifically effectiveness questions are guided toward learner-centered assessment or the demonstration of student learning through learning stream participation. Impact questions are guided toward program assessment or preliminary value judgments on the program based on surveys, focus groups, and other structured activities with the students and faculty involved in the class structure.

The research questions were investigated using methods appropriate for experimental and quasi-experimental studies, including analysis of variance and analysis of covariance linear models for continuous outcomes such as student grades or satisfaction, hierarchical linear models, and structural equation models. Throughout these analyses, the central concern is whether there is a statistically significant main effect on student learning, achievement, and satisfaction attributable to LS participation vs. nonparticipation.

LEARNER-CENTERED ASSESSMENT

Typically students that seek a Computer Engineering degree are required to take three core courses CprE210 Introduction to Digital Design, CprE211 Introduction to Microcontrollers, and CprE305 Computer Organization & Design. Nineteen students enrolled in an accelerated curriculum that replaced the typical three-course core curriculum. CprE 210, 211 and 305 were replaced by CprE281X Digital Logic, Processors and Programming I, and CprE381X Digital Logic, Processors and Programming II. In Fall 2004, 19 students started the CprE 281X/282X course, and 149 students started the CprE 210 class. Learner-centered assessment activities were focused on the differences between the students in each course in order to demonstrate the effectiveness of the experimental program (VIE) versus the typical course structure (Control).

Overall, students in both the VIE and Control classes appeared to have similar training and motivation for the courses. From an assessment perspective, there was initial concern that the students were not randomly assigned to the VIE program, which means that there were concerns about extraneous factors that could confound results. After a review of demographic and statistical variables, there were no statistical differences found between VIE students and Control students based on: sex, age, high school science and math units, ACT or SAT scores, or state residency. The only differences noted were that the Control course included students with majors in non-engineering fields including 29% with major studies in the College of Liberal Arts and Sciences. The Control course also had students that were involved in the honors program, while there were no honors students in the VIE course.

Learner-center assessment was conducted through student-reported understanding on course concepts using pre- and post-surveys. In the Fall 2004, students responded to a pre-course survey web form that asked about knowledge on concepts that would be covered in both courses. At the end of the semester the students were asked the same questions on a post-course survey. Figure 2 displays the averages for the VIE and Control classes on the pre- and post-surveys. The table also displays the average differences between the pre- and post- surveys by class for those students who completed both surveys. The ratings were on a 6-point Likert scale with the following definitions: 1-Unfamiliar, 2-Basic Understanding, 3-Understand and Experiment, 4-Apply Concepts, 5-Proficient, 6-Could Teach This.

The main findings demonstrated preliminary evidence that the VIE students had enhanced conceptual understanding of course concepts in comparison to the Control course. There were no differences among students in the VIE and Control courses on the pre-survey, which demonstrated that students started at about the same level of understanding before the fall semester. Overall means for the VIE students were higher on the post-test, and were significant in four areas. Overall mean differences between the pre- and post-surveys were also greater for VIE students and were significant in four concept areas.

	Fall '04 Pre-Survey			Fall'04 Post-Survey			Pre/Post Difference		
	Control	VIE	Sig.	Control	VIE	Sig.	Control	VIE	Sig.
Number systems and data representation	2.67	3.00		4.13	4.20		1.45	1.89	
Boolean algebra and logic minimization	2.09	2.27		4.07	4.60		2.18	3.11	
Combinational design	1.66	1.93		3.67	4.30		2.36	3.00	
Sequential logic design	1.61	1.93		3.60	4.30		2.54	2.77	
Arithmetic circuits and finite state machines	1.61	1.67		3.47	4.50		2.09	3.11	
Programmable logic devices	1.80	1.67		2.80	4.20	*	1.54	2.67	
Computer aided schematic capture systems	1.94	1.87		3.80	3.70		2.09	1.78	
Simulation tools, and hardware description language	1.88	1.87		3.13	3.90		1.55	2.56	
Design of simple digital systems	1.74	1.40		3.47	3.90	*	2.18	2.89	
Computer organization and design	2.03	2.13		3.00	3.50		1.00	1.78	*
Computer architecture	2.13	1.93		2.67	3.50	*	.64	1.67	*
Assembly language programming	1.72	1.67		2.00	3.20	*	.09	2.00	*
Memory systems	1.73	1.53		2.67	3.40		1.18	2.44	*

$p < .05$

Figure 2: Pre- and Post-Survey Results for Control vs. VIE Groups

Program Assessment

Program assessment was based on focus groups conducted with the VIE students in Fall 2004 and Spring 2005. Overall the students felt the VIE program promoted student-to-student interaction, faculty-to-student interaction, continuity of class material, and encouraged a deep understanding of the course concepts. All students involved in the evaluation exercise would take the sequence of courses again if given the opportunity. Despite student support of the program, they believe that the course structure may not be suitable for all students because it is intense and time-consuming. This section is summarized into prominent themes that emerged through the analysis of focus group notes. Themes are presented in order of perceived importance to the students. As a reminder the 281X and 381X courses refer to the classes taken by the VIE students in the Fall and Spring, respectively.

Theme 1. Continuity in the course structure promoted student learning: Students believe that their learning experience was enhanced by continuity in the structure of the course. Continuous flow of material and lab projects permitted students to have the knowledge needed to begin spring course material or as one student said they could, "pick right up instead of backtracking." Faculty involvement from the fall to the spring semester provided students with an understanding of teaching methods and expectations as well as an opportunity for a connection with the faculty members. Maintenance of the same students in both the 281x and 381x courses provided students with connections to other students that promoted opportunities for small group learning. One student commented that in a class of 80 students (e.g., the 210 and 211 courses), they may know five students, but in a class of 15 students they know all the other students. Laboratory exercises that are cumulative and connected provided opportunities for learning. Cumulative labs over both semesters were described as "very big" and required great understanding to complete. Because they were continuous, one student indicated that he learned more by building a project from start to end, than if the lab exercises were disconnected and unrelated to one another. Another student supported this by indicating the advantage of working at his own pace.

Theme 2. Intense course structure promoted a deep understanding of the material: Because students were enrolled in the course and labs for eight hours per semester, they were deeply immersed in the course material and believed that they had a greater understanding for the concepts. One student indicated that he was able to understand and experiment with the concepts because of the depth of the instruction and labs. Students agreed that they felt the challenge of the course and the heavy requirements for learning this material would benefit them in the future as engineers because they will have better ability to recall the information taught.

Theme 3. Small class structure promoted accountability, interaction, and flexibility: Students believed that the small class structure promoted interaction with other students and faculty. This led to more accountability to instructors and peers, while allowing flexibility based on unforeseeable developments in learning and instruction. Students had a close connection with the two faculty members and had open communication with them about class expectations. As noted earlier, the students had close interaction with one another, so they felt comfortable asking each other for help. Also, the small class structure, combined with the relationships developed among faculty and students, permitted the faculty instruction to be flexible to the learning styles and pace of the students.

Theme 4. Course structure may promote opportunities after completion of the classes: Students felt that there would be benefits of the course structure after completion of the academic year because of the connection between the students to other students, students to the faculty, and the intense learning that took place. Students indicated the relationships formed with other students would be beneficial in their senior year when they will need additional feedback on their senior projects. Students felt that their candidacy for an internship or job after graduation were strengthened because recommendation letters from faculty would be informed by active involvement with them, and that they were better prepared than their peers.

INSTRUCTOR OBSERVATIONS

The instructors, having taught all three courses (CprE 210/211/305), were very familiar with course content and with typical student comprehension of the subject matter, including what is most difficult. In setting up the pilot learning stream of CprE 281/381, it was expected that students would achieve the same learning outcomes as in CprE 210/211/305, with roughly the same topics. The instructors planned the 281/381 organization in detail during summer 2004, so as to develop a comparable set of topics and outcomes. Both lecture and laboratory activities as well as recitation sections were delineated. However, while offering the new sequence, the instructors found that most recitation sections were more productive when combined with lab activities. So a mid-course revision was made, giving students more time in the laboratory. Thus students encountered most concepts in the lab in at least one context (and often more), significantly enhancing the typical lecture-based instruction.

The stream format also afforded a better opportunity to gauge student mastery of concepts, and it provided flexibility in adjusting the schedule to revisit topics as needed. If the instructors determined that students could not apply some concept, either in the lab or on a test, it could be brought back in another context within the flow of the stream. On the second time around, instructors perceived that students typically made the connection to solidify their learning, resulting in deeper understanding than typically possible in a single traditional course. We plan to assess understanding in later courses to determine whether learning stream students did, in fact, reach a higher level of learning compared to their non-learning stream peers.

CONCLUSION

The pilot learning stream implementation at Iowa State shows promising results. The assessment indicates that a stream is an effective alternative to traditional term-based courses. It also revealed areas to improve and to continue monitoring. Overall the stream experience has proven worthwhile for the students participating in the pilot. With favorable early results, we plan to identify other courses that are conceptually related and adaptable to the stream format.

In summary, we believe that the learning stream model is a promising approach to address the need articulated by Bordogna in the following statement [12]:

> "Most curricula require students to learn in unconnected pieces – separate courses whose relationship to each other and to the engineering process are not explained until late in a baccalaureate education, if ever. Further, an engineering education is usually described in terms of a curriculum designed to present to students the set of topics engineers "need to know," leading to the conclusion that an engineering education is a collection of courses. The content of the courses may be valuable, but this view of engineering education appears to ignore the need for connections and for integration – which should be at the core of an engineering education."

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