SECTION C

Case Studies—Projects at the Course and Department Level

Colleges and universities are often heterogeneous collections of departments, schools, or other units—each with a distinct culture. This variability even within institutions makes large-scale transformation exceedingly challenging. Innovation begins often at the course, department, or school level and spreads. The collection of chapters in this section provides case studies for a range of course or curricular innovations. The first three papers describe innovations in engineering education. While all have a similar goal—more broadly educate engineers to possess both the technical knowledge and the problem-solving skills necessary for addressing 21st century challenges—the approaches are quite different. The Vertically Integrated Project model, described by Coyle, builds vertically and horizontally articulated teams. This model, which connects teaching and learning directly to faculty research, started as a course in a single department and has been adopted by several other universities. The iFoundry model, described in the chapter by Sheets, is envisioned as a cross-disciplinary curriculum incubator for testing new courses and programs across an engineering college at a large research university. The third engineering transformation chronicles the creation of a new multi and interdisciplinary engineering program that combines a liberal education with technical knowledge. In contrast to the blank slate approach chronicled by Challah, the PPI program (Mili) presents a purposefully disruptive model for radically changing an entire existing college of technology. The Squires chapter describes a mature five-year redesign of a mathematics department built on faculty teamwork and data-driven decision making for continuous improvement. Finally, Smith's chapter communicates a model of curricular transformation built on collaboration fostered through Faculty Learning Communities.

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The Vertically Integrated Projects (VIP) Program: Leveraging Faculty Research Interests to Transform Undergraduate STEM Education

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Modern universities, especially those classified as research-intensive institutions, are highly fragmented:

- *By Discipline*—With the exception of a handful of faculty with joint appointments in two or more disciplines and a small percentage of students with dual majors, students and faculty are sorted by discipline. There are few opportunities for students to interact in a meaningful way with those in other disciplines. For faculty, there are few incentives or rewards to initiate multidisciplinary collaborations.
- *By Time*—The semester or quarter and the academic year are the fundamental units of time on campuses. Within a semester, the fundamental unit is a credit hour that is associated with a fixed amount of time in a classroom or a laboratory.
- *By Mission*—Universities typically define their missions to be research, education, and service. Commercialization, economic development, and globalization are recent additions to this list. In very few cases are these missions integrated in a way that the boundary between them is not obvious. In fact, most faculty partition each day between their research activities and assigned lecturing in undergraduate or graduate classes.

Efforts to transform higher education must account for this fragmentation. If they do not, any success they achieve will likely be temporary or affect only a small number of students and faculty.

In this paper we report on our effort, the Vertically Integrated Projects (VIP) Program (Coyle, Allebach, & Garton-Krueger, 2006), to address and potentially overcome fragmentation in higher education. The lessons learned when initiating and growing VIP within several institutions have helped to improve the program as measured by the learning outcomes for students, research outcomes

for faculty, and new opportunities for partnering with other organizations. The key has been to leverage faculty interests in and Institutions' reward structures for research, especially when research is defined in a discipline-independent way as *innovation*. VIP provides a mechanism that enables undergraduates to participate in and contribute to innovative efforts led by faculty and their graduate students.

THE VIP PROGRAM

Sustaining and accelerating the pace of innovation in society requires a continuous stream of graduates in all disciplines who understand how the processes of research and technology advancement can be integrated to enable innovation. Current approaches to the education of undergraduates and graduate students are simply not up to this challenge:

- Undergraduates rarely achieve a deep understanding of, or have an opportunity to contribute to any aspect of, their chosen discipline.
- Master's students are typically not involved in either research or the development of new technology/techniques.
- PhD students rarely see their innovative ideas/discoveries have an impact beyond the publication of their theses, conference papers, and journal papers.

We have thus developed a new curricular approach that integrates education and research: the Vertically Integrated Projects (VIP) Program. It creates and supports teams of faculty, graduate students, and undergraduate students that work together on long-term, large-scale projects. The teams are: *multidisciplinary*—drawing students from all disciplines on campus; *vertically-integrated*—maintaining a mix of sophomores through PhD students each semester; *large-scale*—with 10 to 20 undergraduates per team; and *long-term*—each undergraduate may participate in a VIP project for up to three years and projects may last for years, even decades. The continuity, technical depth, and disciplinary breadth of these teams provide:

- The time necessary for students to: learn and practice many different professional skills; make substantial contributions to the project; experience many different roles on a large design/discovery team; and work effectively in a multidisciplinary environment.
- A compelling context: The research efforts of the faculty and graduate students ensures they are engaged because they benefit from the efforts of the undergraduates. It also enables the undergraduates to understand complex issues in their field of interest.

- The mentoring necessary for students to learn about, contribute to, and lead the parts of the project on which they are focused. The mentoring crosses all boundaries, enabling faculty, graduate students, and sophomores through seniors to collaborate successfully.

GOALS OF THE VIP PROGRAM

The goal of the VIP Program is to achieve systemic reform of higher education by:

- Unifying the missions of research and education by enabling undergraduate *teams* to work together with faculty and graduate students in a way that benefits everyone.
- Overcoming the fragmentation by discipline of the university through its focus on large-scale projects that are, almost by necessity, multidisciplinary.
- Eliminating the fragmentation of time in the standard curriculum by enabling projects that last for many years, even decades.

CURRENT STATUS OF VIP AT GEORGIA TECH

There are 300 undergraduates currently enrolled in 27 VIP teams at GT: http://vip.gatech.edu/teams. The teams' advisers are researchers from the following colleges and other organizations on campus: College of Architecture (CoA), College of Computing (CoC), College of Engineering (CoE), College of Science (CoS), Center for Education, Teaching and Learning (CETL), Georgia Tech Research Institute (GTRI), and the Ivan Allen College (IAC).

The primary task so far has been to establish how the VIP courses count toward undergraduate degrees in *each* discipline on campus. Once this is in place for all disciplines, the creation and maintenance of long-term, large-scale, multidisciplinary teams will be possible for almost any ambitious effort that can be envisioned. In the CoC and in ECE and ISyE within the CoE, mechanisms that enable VIP credits to "count" for students' junior and senior design projects have been developed. For the current status of this long-term, multidisciplinary curricular effort, please see: http://vip.gatech.edu/how-vip-credits-count.

Mature VIP teams typically have 12 to 20 students/team, while new teams have six to eight students/team. Students from more than 20 different disciplines are represented on the current set of 27 VIP teams. These students are in some cases from disciplines that have not yet determined how VIP credits count other than as free electives; e.g., psychology and economics.

Faculty request to have teams of their own; they are not required to have VIP teams. To initiate a team, they must demonstrate that the proposed project would be: challenging to undergraduates; last at least four years, preferably more; and have a broad enough goal that the project can evolve based on contributions from everyone on the project, including the undergraduates.

The evaluation of the VIP program is being led by Julia Melkers of Public Policy. With NSF support and support from a GT Global-FIRE grant, she has been characterizing knowledge exchange amongst the students both within and between VIP teams. She has also been evaluating the learning outcomes for students who participate in the VIP Program [Melkers, et al, 2012]. These results build on earlier efforts to evaluate the effect of vertically integrated project teams on students' development of both disciplinary and professional skills (Coyle, Jamieson, & Oakes, 2005). Melkers has recently received IRB approval

FIGURE 1. The Fall 2010 eStadium VIP team. They design, develop, and deploy systems that enable studies of wireless network traffic during football games. Fans in the stands go to: http://estadium.gatech.edu/iphone to access stats and on-demand video clips of plays for GT football games. Students from CEE, ECE, CS, and ISyE participate in the team. They also design social network apps and wireless sensor networks.

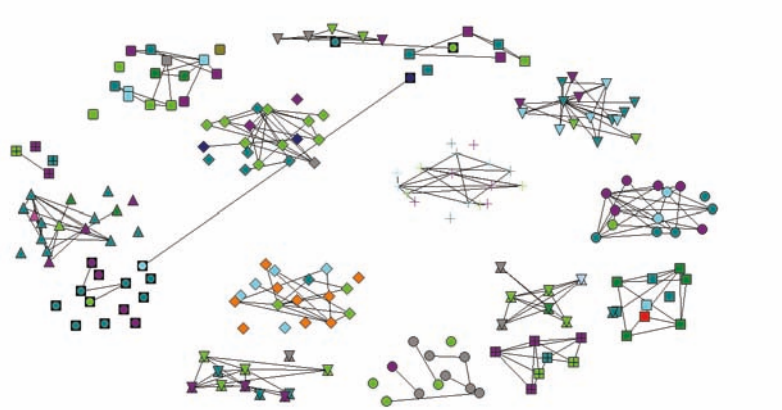

FIGURE 2. A network showing the exchange of technical information within and between VIP teams for the Fall 2011 semester at Georgia Tech. Students on the same team are grouped together and represented by a common shape (square, triangle, plus-sign, etc.). The colors represent the disciplines of the students. The mostly disconnected subgraph in the lower left is a team with a hub-and-spoke advising model, with the adviser meeting and working one-on-one with each student. New teams tend to be smaller in size (4-8 students) than more mature teams (12+ students).

to use, after obtaining appropriate written permission from them, students' grades within VIP and in the curriculum in general to determine the effect of VIP on student learning. This will enable the evaluation of VIP to progress well beyond the students' self-reported data from surveys and interviews that are currently used.

BENEFITS OF VIP FOR STUDENTS

The VIP Program provides many benefits to undergraduate students, graduate students and faculty. The most important of the benefits is the way it enables members of all of three groups to form a *community* in which they work together over an extended period of time on a project of common interest. This experience builds mutual respect, cultivates curiosity and creativity, enables meaningful collaborations on both a disciplinary and personal basis, and provides benefits to all participants in the project.

The benefits to the undergraduates who participate in VIP include, but are not limited to:

- The opportunity to apply what they are learning in their regular coursework to real, challenging problems that are of current interest in their field.

- Learning to work with and eventually take a leadership role in a sophisticated team that is working on a challenging project.
- Development and regular honing of professional skills, including: oral and written communication ability, making presentations to a variety of audiences, collaborative brainstorming and problem solving, developing resilience in the face of failure, etc.
- Becoming a truly active/independent/life-long learner and a creative problem solver.
- Learning about cutting-edge issues in their discipline.
- Achieving significant depth of expertise in some aspect of their home discipline.
- Learning how to communicate and work productively with people from other disciplines and widely varying backgrounds.
- Learning how to "come up to speed" on and then contribute to a large-scale, intellectually ambitious project.
- Learning that challenging problems may have many possible solutions and even many approaches to defining them.
- Experiencing the great satisfaction of solving a challenging problem, designing a complex system and seeing it work as intended, or discovering a new way of looking at an issue or problem.
- Learning to be a creative, resourceful, self-motivated, and responsible member of a team.
- Learning to adapt as situations change and to recover/restart after setbacks.

Many students have already reported that when they interview for jobs after participating in VIP, that their experiences and accomplishments on their VIP team quickly become the focus of the interview. A number of innovations produced by VIP students have been patented/copyrighted and licensed. We also believe that it is only a matter of time before there are a number of successful commercialization efforts based on VIP projects.

BENEFITS OF VIP TO THE UNIVERSITY

The benefits of VIP to students and faculty are measurable, as are benefits to the university. We believe that there are additional benefits to universities, although they are perhaps harder to measure:

- Provides students with a compelling reason to be on campus, even in an age of MOOCs and other distance education approaches.

- Enhances innovation on campus by enabling everyone to participate.
- Enables projects of large scope and duration to be attempted.
- Enables new partnerships with organizations both on and off campus.
- Opens up and deepens multidisciplinary opportunities across campus.
- Deepens and broadens the university community by providing an environment in which faculty, graduate students, and undergraduate students can get to know each other very well.

CHARACTERISTICS OF FIVE VIP PROGRAMS

In this section, we describe five VIP Programs—those at Georgia Tech, Morehouse College, Purdue University, University of Michigan, and the University of Strathclyde—in terms of origin and type of implementation strategy; number of disciplines involved; type of institution; implementation in the curriculum; resources and support available; growth of the program; grading/assessment strategy and tools; relationship with other discovery and design programs; software tools for program administration; and number of students and faculty involved. In some cases, fewer than five programs will be described, as appropriate.

Origins, Institutions, and Numbers of Disciplines, Faculty and Students Involved

The VIP Program was launched at Purdue University in 2001 with the creation of the first VIP team, the eStadium team. VIP was designed to improve upon its predecessor, the Engineering Projects in Community Service (EPICS) Program (Coyle, Jamieson, & Oakes, 2005). Both of these programs at Purdue used large-scale, long-term teams composed of undergraduates that could register for credit for up to three years. The difference between them was the context of the projects. In EPICS, the teams designed, developed and deployed products and systems for non-profit organizations in the local community. In VIP, the teams design, develop and deploy products and systems that assist faculty and their graduate students with their research. The hypothesis was that more faculty would be willing to advise teams for many years if doing so would benefit their research activity, for which they are regularly rewarded.

The choice of VIP as the name of the new program focused on the mechanism that enabled the teams to function well, as opposed to the discipline(s) on which the program was focused, which was engineering in the case of EPICS. The result is that VIP has spread to many disciplines besides engineering, including architecture, business, computing, the humanities, public policy, and science.

At Purdue, VIP grew primarily within Electrical and Computer Engineering, but has also spread to other disciplines over time, including Aeronautics and Astronautics, Human Development and Family Studies, and Earth, Atmospheric and Planetary Sciences. There are currently 14 VIP teams at Purdue.

VIP spread to Georgia Tech in 2009 and was founded with the intent of being a campus-wide program and on developing processes and tools that would enable it to grow to support many teams. There are currently 300 undergraduates enrolled in 27 VIP teams. The teams' advisers and students involved come from four colleges—Architecture, Computing, Engineering, and Science—and such organizations as the Georgia Tech Research Institute; the Center for Education, Teaching, and Learning; and the Centers for Disease Control.

In 2010, a VIP team was created at Morehouse College. The team collaborated with the eStadium VIP team at Georgia Tech. This enabled a research focus and access to a large stadium that were not available at Morehouse. The team functioned for three semesters. Efforts are underway to develop an effective way for VIP to function at Morehouse, where faculty teaching loads are higher than at R-I universities like Georgia Tech.

In 2011, VIP was implemented at the University of Strathclyde in Glasgow, Scotland. It started in many different disciplines simultaneously, including Biology, Computing, Engineering, English, and Management. There are currently 10 VIP teams at Strathclyde.

Other universities have started VIP-like programs, including projects within the University of Michigan's Multidisciplinary Design Program (Daly, Bell, Gilchrist, Hohner, & Paul Holloway, 2011) http://mdp.engin.umich.edu and Texas A&M's AggiE-Challenge, which currently fields 13 teams:

http://engineering.tamu.edu/easa/areas/enrichment/aggie-challenge

Implementation in the Curriculum

It is critical that curricular implementation of VIP provide incentives for students to participate for at least two years. The School of Electrical and Computer Engineering at Georgia Tech approved guidelines for VIP credits, described below, that provide an example of how VIP can be integrated into senior design. To encourage long-term student participation, VIP credits cannot be used as ECE electives unless students take six or more credits of VIP, as per the following guidelines.

NOTE: There is a six-credit limit on the following types of courses: Independent Research, Special Problems and VIP. Students can take all three types of courses, but only six credits can be applied toward the degree. Students

interested in doing more than six credits of VIP should consider using VIP for Senior Design, which allows for an additional semester of VIP participation through the Senior Design course. To do this, students must follow a specific timeline.

For students not using VIP projects for Senior Design:

If five or fewer VIP credits are earned:
Five credits can be used as approved electives.
During the junior year (or after ECE 2031), VIP can be used to fulfill the ECE 3006 Professional Communications requirement.

If six VIP credits are earned with the same team:
Three credits can be used as ECE electives.
Three credits can be used as approved electives.
During the junior year (or after ECE 2031), VIP can be used to fulfill the ECE 3006 Professional Communications requirement.

For students using VIP for Senior Design, at least five VIP credits will be earned with the same team prior to Senior Design (per the required timeline):

Three credits can be used as ECE electives.
Two to three credits can be used as approved electives.
During the junior year (or after ECE 2031), VIP can be used to fulfill the ECE 3006 Professional Communications requirement.
Three Senior Design Credits: The student will register for the VIP section of Senior Design, with the technical portion of the students' design experience completed as a member of the student's VIP team.

An explicit timeline for this process is available at:

http://www.vip.gatech.edu/how-credits-count-electrical-computer-engineering

Resources and Support

Resources available for VIP programs depend upon the size and age of the program. The most common element in a VIP Program is a research-active faculty member who serves as the director and is also the adviser for a team. Once a program has at least 10 to 12 teams, a program manager is necessary to assist with operations. With the addition of software tools for processing permits to participate in the program, for grading and peer evaluations, and the unique IT needs of the program, it can expand significantly. We believe at this time that

with these resources, a VIP Program that fields hundreds of teams with thousands of students is feasible.

One unique resource available to the Georgia Tech VIP Program is a co-director for technology, Randal Abler, who in addition to other tasks, defines and develops technology solutions to assist with both program and team operations.

Tools for Program Administration and Growth

Tools that have been developed to enable both scaling and evaluation of student outcomes include:

- On-line team advertising combined with a process for students to apply to join a team of their choice.
- Course-permit administration tools to assign students to teams.
- Grading and peer evaluation tools and a database used by all advisers/teams. IRB approval has been obtained to enable program evaluators to access grades in these databases.

THE VIP CONSORTIUM

Sixteen universities have recently created the *VIP Consortium*. It consists of schools that have or plan to adopt the VIP model and have committed to collaborate to improve and expand it. Schools in the U.S. that have already fielded VIP teams are Georgia Tech, Purdue University, and Morehouse College. Please see the website of the Purdue VIP Program: https://engineering.purdue.edu/vip. Schools in the U.S. that have programs very similar to VIP include the University of Michigan and Texas A&M University. Internationally, the University of Strathclyde and National Ilan University in Taiwan have created VIP Programs.

The universities that have formed the VIP Consortium are: Boise State University, Colorado State University, Florida International University, Georgia Tech, Howard University, Morehouse College, National Ilan University, Purdue University, Rice University, Texas A&M, University of Hawaii—Manoa, University of Michigan, University of Strathclyde, University of Washington, and Virginia Commonwealth University. The rapid dissemination of the VIP model to other universities is confirmation of the compelling nature of the educational *and* research benefits of the program. It is also a unique opportunity to achieve systemic reform on a national scale.

The University of Strathclyde in Glasgow, Scotland has an active VIP Program, currently fielding 10 VIP teams: http://www.strath.ac.uk/viprojects. They were the first non-U.S. university to participate in the consortium. Their experiences and challenges in creating and sustaining VIP have been quite different

than those of U.S. institutions. Their insights have already been of significant value to the consortium's effort.

The creation of the VIP Consortium is being supported by a $5M grant from the Leona M. and Harry B. Helmsley Charitable Trust. The grant, which started Jan 1, 2015, supports U.S. institutions' participation in consortium-wide efforts to develop and share ideas, processes and software tools that enhance the operation, growth and evaluation of all VIP Programs. Georgia Tech is the lead institution of the consortium, and the University of Michigan is the co-lead.

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