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CUR Focus

Connecting Business and STEM Education Through Undergraduate Research

Business is inherently interdisciplinary. The practices, policies, and norms that govern business are grounded in social science, and the goods and services that businesses produce are themselves the fruits of science, engineering, arts, and humanities. Business also plays an essential role in translating advances in the arts and sciences into public benefits and shaping humanity's impact on our planet. Thus, it is increasingly being recognized that business education also must be interdisciplinary to meet the needs of today's businesses (Colby et al. 2011; Hardy and Everett 2013; Shulman 2011).

This interdependency is particularly apparent for the sciences, which depend on for-profit and non-profit businesses to translate insights and inventions arising from scientific research into products and services that are of value to the public. Indeed, there is an extensive literature on industry's growing need for a workforce of professionals in the fields of science, technology, engineering, and mathematics (STEM) who have the interdisciplinary technical, social, and business skills required to work productively in a business environment (PKAL 2006; PCAST 2012; NAS 2007; NAE 2002). The emergence of the professional science master's (PSM) degree programs, for example, is specifically aimed at meeting this need (NRC 2008).

It is also recognized that there is a growing need for business professionals who are capable of integrating science and technology into corporate strategies and management (McCann 2006; Ledley and Holt 2014; Ledley and Oches 2013; Ledley 2012). Benchmarking studies of technology management suggest that CEOs and business-unit managers are often directly responsible for decisions regarding technology, research, and development (Lichtenthaler 2003; Elder, Meyer-Krahmer, and Reger 2002). Research suggests that to function effectively in such corporate roles, business leaders must have: (1) an interdisciplinary knowledge of science and technology, which has been described as "a sophisticated appreciation of their nature, as well as of their economic, social, and ethical consequences" (McCann 2006); (2) the ability to "understand the technical issues facing their organizations and the portfolio of ideas and projects that are in the pipeline at any time" (Harvard Business Essentials 2003); and (3) "technology-centered knowledge" related to the nature of science and technology, the strategic role of technology in business, the implementation of technology, and the process of technological innovation (IAMOT 2007; Mallick and Chaudhury 2000).

In other articles, we have addressed the role of the undergraduate science curriculum in providing business students with the interdisciplinary skills to function effectively in a technology-intense business environment (Ledley 2012; Ledley and Holt 2014; Ledley and Oches 2013). While most business majors take "introductory" science as part of their general-education requirements (Ledley 2012), these traditional science courses for non-majors often provide little context for applying scientific learning outside of the particular discipline. Moreover, such courses are classically "introductory" in nature, even though for most business students, they represent their last formal experience with science education (Labov 2004). We have proposed that interdisciplinary education might be advanced both by developing undergraduate science courses with pedagogy and learning objectives designed explicitly for business students (Ledley 2012; Ledley and Oches 2013), and also by the reciprocal integration of business principles into science courses by utilizing teaching modules and case studies that contextualize scientific principles within a business curriculum (Szymanski et al. unpublished).

Here we describe the use of undergraduate research to foster interdisciplinary STEM and business learning at a "business university." Our program differs from other undergraduate STEM programs in that the primary goal of undergraduate research is not to promote STEM careers or graduate study, but rather to highlight connections among STEM enterprises, business, and society. We describe our experience at Bentley University, where more than 95 percent of our students major in a business discipline. Bentley provides a living laboratory for studying how to advance STEM education for business students in general. We describe three different models for undergraduate research: (1) engaging business students in disciplinary STEM research; (2) engaging business students in STEM research connected to service; and (3) engaging business students in the integration of science and industry. Additionally, we address what business students bring to undergraduate research in terms of attitudes and learning styles that may be particularly conducive to informal science learning, and we consider how undergraduate research can help business students achieve the higher goals of liberal education.

The Bentley Business Curriculum

The business curriculum at Bentley is highly structured and includes several components: a disciplinary major of eight to 12 courses (24–36 credits), a "general business" core requirement of nine specific courses (27 credits), and a general-education requirement of 15 courses in different disciplines of the arts and sciences (46 credits). The curriculum is designed in accordance with the accreditation standards of the American Association of Collegiate Schools of Business (AACSB 2012). Throughout the curriculum, there is an emphasis on the "fusion" of business and the arts and sciences (Hardy and Everett 2013). This is evident in the integration of liberal-learning objectives—as exemplified by the Liberal Education America's Promise (LEAP) Essential Learning Outcomes (NLCLEAP 2011)—into our business curriculum and the integration of business and work perspectives into the arts-and-science curriculum. Bentley University also has a long tradition of engaging business students in service learning and civic engagement, described in numerous publications (Zlotkowski 1996; Salimbene et al. 2005; Szymanski, Hadlock, and Zlotkowski 2012).

Bentley students are required to take one laboratory-based science course and one elective in either math or science, somewhat fewer courses than the average requirement of two laboratory-science courses common among business programs in *BusinessWeek's* "top 50" (Ledley 2012). Bentley did not offer a science major until 2013, although approximately 60 students a year graduate with a second liberal studies major in Earth, Environment, and Global Sustainability or in Health and Industry. These complementary majors generally require four to five science courses (including psychology).

Given a highly structured curriculum and a limited number of students enrolled in science-based programs, we identified undergraduate research as an important opportunity for engaging students in additional STEM learning added to their business curriculum. We have taken a broad approach to undergraduate research in STEM fields, building on the strength of our faculty's disciplinary research, civic engagement, and the work of our Center for Integration of Science and Industry (described below).

UR for Business Students: Three Models

Undergraduate research is not a monolithic enterprise, but refers broadly to engaging undergraduates in inquiry or investigative projects to establish facts or create new knowledge (Wenzel 1997), in conjunction with the scholarly activities of the university's faculty. At Bentley University, we have developed three different formats for undergraduate research: STEM research with science faculty, STEM research embedded in class-based projects and service learning, and research focused explicitly on integrating science and business to advance translational science.

While very few of our students will pursue STEM careers or graduate study, many will work in science- and technology-intensive industries. Our internal studies suggest that, while students who choose a business university express little interest in becoming scientists, most are interested in science and its promise. Thus our undergraduate research initiatives are designed to promote this interest and the interdisciplinary literacy and facility with science that will be increasingly required in business careers.

Engaging business students in disciplinary STEM research

Faculty in Bentley's Department of Natural and Applied Sciences have active research programs in fields ranging from climate change, green chemistry, environmental chemistry, and sustainability, to malaria control, epidemiology, health communications, healthcare practices, and drug development. As at other academic institutions of our scale, undergraduates are actively recruited to work in the department and contribute to faculty members' research. Recent projects that have engaged undergraduates have included field studies to collect sediments and fossils for climate research and the physicochemical analysis of those samples; watershed-scale environmental studies; construction of numerical models of infectious diseases; and enzyme-catalyzed synthesis of polymers. Several students have presented their work at national meetings and have been recognized as coauthors of resulting publications.

Bentley student, Thomas J. Klement, '16, synthesizes nontoxic flame-retardant polymers utilizing green chemistry techniques.

Students often express some reluctance to engage in scientific research, feeling that they are outsiders to the culture of a science department and do not have adequate technical skills. Those feelings often disappear as they receive faculty

mentoring that helps them acquire essential laboratory skills and that encourages them to engage in both the excitement of scientific discoveries and analysis of their economic or social impacts. This mentoring also creates an environment in which students recognize that they are essential members of a research team, which in turn encourages them to become actively involved in their own learning.

Several characteristic elements of business education at Bentley can be translated into the research environment. First, the strong focus on group work and the social dynamics of teams in the business curriculum help students become effective members of the research team. Second, the widespread use of case studies as a pedagogical tool prepares students with analytical and problem-solving skills, decision-making scenarios, and the ability to work with ambiguities (Dunne and Brooks 2004) that are often directly relevant in a research environment. Finally, the business orientation and goals of our students often lead them to creative insights into how their research might be translated into commercially successful products and services.

Engaging business students in STEM research connected to service

Engaging students in undergraduate research in the context of providing service to the broader community provides a powerful opportunity to enhance students' understanding about the links among STEM fields, business, and society.

Primary research centered on a public problem can place STEM and business issues into a civic context and lead students to generate specific recommendations for policymakers at the local, state, or federal levels (Szymanski, Hadlock, and Zlotkowski 2012). At Bentley, for example, students taking a seminar on the science in environmental policy have addressed issues related to federal energy and environmental policies in a service-learning project by conducting primary research for a nonprofit organization in Washington, D.C. At the end of a semester of research, students traveled to Capitol Hill to present their recommendations to lawmakers. As described by Szymanski, Hadlock, and Zlotkowski (2012), initial efforts to help students provide lawmakers with data-driven and pragmatic policy recommendations have been highly successful in terms of impact, pedagogy, and what Colby et al. (2011) describe as the reflective exploration of meaning.

In a recent offering of the same seminar course described above (Szymanski, Hadlock, and Zlotkowski 2012), a student team worked with several D.C.-based nonprofit organizations to study the impact of consumers' energy literacy on U.S. workforce development and consumer spending. Drawing on disciplinary studies in STEM, accounting, and economic fields, one student initiated a subsequent research partnership with National Grid—a multinational electricity and gas utility—to study how increased energy literacy among consumers may save individuals and the nation money. Still in progress, this econometric study has yielded more than 3,500 data points that link energy literacy with energy consumption. Undergraduate research that identifies society as a stakeholder applies core concepts from both science and business and provides students with a new sense of empowerment in civic affairs.

Bentley business students engaged in service-learning research meet with Gina McCarthy (center), Environmental Protection Agency Administrator, during their study of the impact of energy literacy on U.S. workforce development and consumer spending. Students, L to R: Kaila Reed '14, Aaron Pinet '14, Laura Yates '13, Alyson Bisceglia '13, Ryan Vermette '13, Monica Tshanakas '13, and Daniel Westervelt '15.

Engaging business students in the integration of science and industry

Bentley's Center for Integration of Science and Industry researches the path by which scientific insights and inventions are translated into public value in the form of new products and services that meet personal and public needs, as well as jobs and sustainable economic growth. An extensive body of business research suggests that translational science requires a critical synergy between the potential of new technologies at any point in time, and the business models that provide the resources, processes, and values required for successful development and dissemination of the product (Christensen and Raynor 2003). Thus, the center's research requires scientific and technological knowledge, as well as knowledge of corporate finance, accounting, markets, strategy, business development, and management.

The interdisciplinary perspectives that underlie the Center's work are achieved by incorporating undergraduate business students into research teams that include post-doctoral scientists with PhDs in STEM disciplines, along with "executives in residence" from the biotechnology and investment communities. The students' role on these teams mirrors the role of business professionals in industry whose training in investment, finance, management, strategy, and markets must

complement the insights into technologies provided by PhD scientists, in order to advance translational science. For example, undergraduate researchers have conducted research examining: the relationship between capital investments in biotechnology companies developing gene therapies and the characteristics of each company's core technology; the relationship between the maturity of biotechnology companies' core technologies at the time of their initial public offering (IPO) and the company's performance and success in product development over the ensuing 10 years; and the relationship among funding for cancer research, the measured rate of progress of cancer research, and the number of approved anticancer drugs.

In these projects, students have applied their business education to analyze data on capital investments, corporate valuations, business models and transactions, and product pipelines, while at the same time learning about discoveries at the forefront of science, how science progresses, what it costs, and why it succeeds or fails. They learn the importance of interdisciplinary knowledge in technology-intensive industries, and the discipline required to perform professional-quality business analysis. Students often contribute substantive insights into the asynchronies between technological maturation and investment activity that may delay the translation of promising technologies into new products, as well as business strategies and policies that might accelerate this translation. Through their work at the center, most students earn co-authorship on the center's publications.

Bentley student, Peter Connolly (center), '14, (center) works with biotechnology Executives in Residence Michael Boss and Nancy Hsiung at the Center for Integration of Science and Industry.

Our initial view of the value of this integrative program comes from an informal, interview-based assessment of our undergraduate research program performed by the executives in residence for the foundation that funds the center. These unstructured interviews with all of the students working with the center suggest that one of the most valuable parts of the experience is the opportunity to interact with the scientific and business professionals on our research teams. Many students also comment on the challenge of applying the lessons from their business courses to "real world" tests, the value of the inquiry, and the quantitative analytical skills that are acquired during their projects. Many students also detail how the experience contributed to their success in obtaining internships and in job interviews.

Learning Styles, Curricular Fusion

Historically, students at business universities perceive the arts-and-sciences curriculum or general-education core as hoops that they have to jump through, unconnected to their goal of studying business. Curricula at business universities have been presented as silos of general education, the business core and the major, with unfortunate consequences. Two significant motivating factors for business students are future employment and relevance of theory to practice (Goorha and Mohan 2010; Von Der Heidt and Lamberton 2011). Until recently, business universities neglected to demonstrate a relationship between the arts-and-sciences curriculum and the professional life of someone in business. The importance of developing knowledge regarding the interrelationship of disciplines was even more poorly communicated to business students seeking pragmatic relevance and utility for their learning. This may have been especially true for science education, where the familiar student refrain was, "Why do I have to learn this? I will never use it."

Research by cognitive psychologists on undergraduates' attitudes, learning styles, and preferred pedagogies has increased six-fold over the past forty years (Armstrong, Cools, and Sadler-Smith 2012). While there is evidence of some degree of learning-style preferences and attitudes among business students, there may be other factors influencing student attitudes toward science research. It may not be that business students dislike science curricula due to attitudes or learning styles. Rather, institutional culture, explicit messaging regarding curricular relevance to career, and practical application of theory to contemporary problems may be more significant motivating factors.

Kolb's (1984) Learning Styles Inventory (LSI) is among the most frequent taxonomy applied to students in undergraduate business programs. The LSI includes four learning styles. First, the *diverging style* is characterized by students who prefer information presented from various points of view. The *assimilating style* describes students who prefer to convert disparate information into a coherent whole. Students possessing the *convergent style* seek to find practical utility for theoretical concepts. Finally, the *accommodating style* describes students who prefer to learn by doing.

Business undergraduates possess characteristics of each of Kolb's four learning styles (Kolb and Kolb 2005). "Business students learn by reflecting on a concept and making observations, abstractly conceptualizing the concept by drawing on these reflections, and by applying the concept through experimentation" (Goorha and Mohan 2010, 148). Fortunately, these are the skills and learning styles necessary for successful and fulfilling undergraduate science research.

The degree to which the pedagogy for undergraduate research in STEM fields is aligned with the institutional culture and with the broader learning experiences of students across disciplines will influence the attitudes students develop toward science education. Thus Bentley University has transformed its intellectual culture in the sciences, abandoning the historical silo model to stress interdisciplinary perspectives and ultimately producing a model of fusion between arts-and-sciences and business curricula. The current model emphasizes the value of transdisciplinary perspectives in addressing the complex challenges that confront business and society. Bentley students are engaged collaboratively in applying theory to practice in simulations from business laboratories to science labs. Service learning, capstone projects for the honors program or liberal studies major, and undergraduate research each provide students with opportunities to apply theoretical perspectives gained in the classroom to real-world social and policy issues.

Bentley has infused experiential learning and faculty mentoring throughout the curriculum. The pedagogical models for undergraduate STEM research are integrated and consistent with this emerging Bentley culture. Through these models, students have developed a deeper appreciation of the relevance of STEM education to business and society.

Of course, applying classroom learning outside of any individual discipline requires an understanding of the application of scientific knowledge, and also a sense of the transdisciplinary nature of complex problems (Szymanski et al. unpublished). For example, addressing problems of global economic and environmental sustainability requires changing the way we educate both STEM and non-STEM majors to think about their roles in the complex systems of commerce, technology, and civic life (Hardy and Everett 2013; Ledley and Oches 2013). These systems can only be understood in a transdisciplinary context that blends concepts from different disciplines and then demonstrates how they can be integrated to contextualize complex problems. Industry is pleading for this kind of STEM literacy (Szymanski 2013; NRC 2014). Practically, this means liberal learning, professional education, and civic engagement must be de-compartmentalized to help students comprehend, if not solve, some of the most pressing issues of society. This fusion of liberal education and business education is what Lee Shulman (2011) calls "reciprocal integration" in his foreword to the Carnegie Foundation for the Advancement of Teaching's report "Rethinking Undergraduate Business Education" (Colby et al. 2011). Undergraduate research provides many business students with their first exposure to the complexity of the reciprocal integration that is required to solve real-world challenges.

In addition *to practical reasoning*—the essence of professional education that links knowledge with practice—Anne Colby and her colleagues point to three kinds of liberal learning that are essential to reciprocal integration: *analytical thinking, multiple framing,* and *reflective exploration of meaning*. Each of these elements is embodied in the undergraduate research experience, in which students are asked to engage outside of disciplinary reasoning and habits-of-mind, engage in the analytical process of science, and explore the connections among science, industry, and society.

Finally, undergraduate STEM research, particularly in conjunction with service learning or working to accelerate the translation of scientific advances into public value, can empower students to help address critical public issues at a variety of levels. In these cases, service learning challenges students to ask, "What difference does a particular understanding or approach to things make to who I am, how I engage the world, and what it is reasonable for me to imagine and hope?" (Colby et al. 2011).

Implications

In this article, we describe the use of undergraduate research to integrate STEM learning into a structured business program. Building on existing strengths in science research, civic engagement, and Bentley's Center for Integration of Science and Industry, we have explored three distinct avenues to introduce business students to scientific inquiry and discovery. These models include projects designed to (1) engage business students in disciplinary STEM research; (2) engage business students in STEM research connected to service; and (3) engage business students in the integration of science and industry. These pedagogical models are integrated and consistent with an emerging culture of fusion between experiential learning and faculty mentoring at Bentley. In our experience, business students are eager to integrate science into their business careers, become highly engaged with their research mentors, and bring valuable skills to research teams trying to integrate research outcomes, business practices, and societal value. Many earn co-authorship on academic publications and present at professional meetings. As a result, the students believe their research experiences extend both their business and scientific skills and ultimately contribute directly to their success in internships, job inter-

views, and emerging business careers. Like the professional science master's degree, undergraduate research connecting science and business can help provide future business leaders with the interdisciplinary skills that they, and their businesses, need to succeed.

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