

Innovating How to Learn Design Thinking, Making, and Innovation: Incorporating Multiple Modes in Teaching the Innovation Process

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Abstract. Faculty in business and engineering schools are increasingly focused on teaching the fundamentals of the innovation process to students at all levels. There has been a recent embrace of teaching the innovation process through a user-centered “design thinking” methodology and on experiential “making” activities within interdisciplinary teams. Although valuable as part of an innovation curriculum, a focus on only one set of tools and methods such as design thinking may detract from other valuable approaches, thereby limiting the full range of incremental to radical innovation outcomes that students need to learn to be effective innovation leaders. In this essay we review pedagogy related to teaching innovation processes, and we categorize approaches into four modes depending on teaching method (experiential or analytical) and participant context (disciplinary or interdisciplinary). We propose that in order to teach innovation effectively, students need to be exposed to all four modes, where learning opportunities differ. We illustrate our points drawing from courses among multiple settings, and we provide implications for curriculum design that will help faculty to innovate how they teach innovation.



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1. Introduction

Teaching the fundamentals of an innovation process—how to develop and introduce new products, services, and business models—has become widespread in business schools (Dyer et al. 2009, Thursby et al. 2009). One method increasingly used is to focus on a “design thinking” approach (Dunne and Martin 2006, Fixson 2009, Fixson and Read 2012, Glen et al. 2014), and the use of design thinking is not only confined to business schools but also can touch the wider university (Boni et al. 2009, Thursby et al. 2009). Design thinking promotes the use of interdisciplinary student teams in developing innovations through gaining a deep understanding of users (Boni et al. 2009, Glen et al. 2014), while drawing upon long-standing features of experiential learning (Kolb 1984) such as employing prototype “making” activities (Wilczynski 2015). Design thinking shifts traditional business school analytical approaches to experiential learning through applying

human-centered approaches to develop better opportunities and solutions. An experiential-interdisciplinary foundation is at the heart of a design thinking approach to teaching innovation. Although there has recently been great enthusiasm for design thinking, it is but one approach and set of associated skills. What other approaches to teaching should be considered in a comprehensive innovation curriculum?

Faculty seek to prepare students for careers in an economy that embraces innovation as an overarching theme (Thursby et al. 2009), but not all innovation is the same. Research over the last 30 years has introduced a number of ways to envision how innovation comes about and its effect, with labels such as architectural innovation, disruptive innovation, and business model innovation (Henderson and Clark 1990, Christensen 1997, Pisano, 2015). These different types of innovation build on a fundamental dichotomy that spans from more incremental to more radical innovation.

Pursuing a portfolio including both incremental and radical innovations is seen by most scholars as critical to a firm's success (e.g., Pisano 2015, Sahal 1981); however, developing a full range of innovations may need different training and a different approach. Incremental innovation that focuses on making improvements within an established technological paradigm may require skills that are distinct from radical innovation that focuses on combining skills in very different ways. Teaching innovation using merely one approach might not necessarily cover a complete toolkit of what students need to address all types of innovation. Employing multiple approaches may be particularly important for future business leaders that have to contend with rapid technology cycles, new business models, and new information technology tools such as blockchain and artificial intelligence—as well as the increased importance of services in the global economy.

In this essay we provide an analysis of some relevant pedagogical dimensions as well as a history of major approaches to teaching the innovation process, with the intent to provide perspective on the range of approaches that are appropriate to consider in curriculum design. As innovation has moved from the purview of engineering schools to include business schools, design thinking as a method has gained prominence. There can be a legitimate concern that the trend to focus on design thinking may distract faculty from considering a broader range of learning experiences for students, and this may in turn lead to an overemphasis on incremental innovations. Although we are tremendous supporters of the experiential-interdisciplinary education encapsulated in design thinking efforts, we believe it is important to understand the benefits of a range of learning experiences that will not all be available in any single course.

Drawing from existing literature and illustrated with examples from our own courses and several examples from universities around the world, in this essay we propose that to properly design and deliver a curriculum focused on the innovation process, one needs to consider two main dimensions. The first dimension we focus on is the teaching method, and whether it is focused on analysis or on experiential learning. The second dimension we highlight is focused on the participant context, and whether learning takes place in a disciplinary or interdisciplinary environment. These two dimensions lead to four distinct modes to teaching innovation, which we will review in turn. Each mode meets specific student and institutional needs and is more or less suited to teaching concepts related to incremental versus radical innovation. Rather than seek out one approach to providing an innovation course, such as one dedicated to design thinking, faculty should consider how all four

modes have a place in a comprehensive curriculum devoted to teaching and learning the innovation process.

2. Innovation Objectives and Key Pedagogical Dimensions

Our intent is to provide faculty with a framework to think about how their curriculum can help prepare students to address a range of innovation objectives by considering some key pedagogical dimensions that are important to include across the courses offered. In this section, we will first describe how the objectives of innovation span incremental and radical outcomes, and then we will describe the two key pedagogical dimensions that support coursework on the innovation process. In a further section, we review the main approaches to teaching innovation across these dimensions. The final major section describes the main implications for curriculum design and provides an example curriculum spanning these dimensions.

2.1. Innovation Objectives: Incremental vs. Radical Outcomes

Scholars have long noted that the objective of innovation is not always the same, and have identified that the outcome of innovation can span from incremental to radical (Sahal 1981, Tushman and Anderson 1986). For example, incremental innovations often build on a firm's past competencies and an established dominant design, and these innovations are a means by which a firm can improve performance without significant changes in strategy. In contrast, radical innovations often require a new combination of competencies that may challenge incumbent firms, providing a higher potential reward albeit with more inherent risk (Tushman and Anderson 1986).

Both incremental and radical innovation objectives underpin the innovation strategies of firms (Pisano 2015). For example, in the automotive industry, an incremental innovation project may be concerned with the development of the next-generation battery for an existing line of hybrid cars, and a radical innovation project may include the research behind entirely new fuel-cell technologies. Incremental versus radical innovations could also be seen in service innovation, with one firm pursuing an incremental innovation project on a new maintenance platform for their dealers, and a start-up developing a radical approach for car sharing.

Of course, the development of many products and services is not simply incremental or radical but rather involves a range of innovations across components, subsystems, and architectures. Innovation research over the past several decades has expanded our understanding of the various mechanisms that can make innovations succeed. As examples of findings,

some incremental innovations can succeed by rearranging existing components in new architectures (Henderson and Clark 1990), and some seemingly inferior technologies can disrupt incumbent technologies from below (Christensen 1997). In a contemporary context, an ambidexterity of working across incremental and radical concepts is increasingly important as firms face pressure to apply these concepts to new business models and service concepts, such as in how ride-sharing applications combine existing resources in new ways to provide new services using new business models.

Although past richness in innovation research is reflected in many courses that we will discuss, and contemporary examples are often a blend of approaches, our organizing focus in this essay will be on the fundamental dimension that often underlies innovation management challenges: How can one address the need for both incremental and radical innovation, each of which exhibits very different managerial and technological dynamics? As a result, any curriculum will need to help students face a range of innovation challenges that span the spectrum ranging from evolutionary to revolutionary outcomes, while understanding how many innovations blend contributions from across the spectrum.

2.2. Two Key Pedagogical Dimensions

There are many different means by which an approach to teaching can be classified, but past research on pedagogy broadly often highlights two dimensions as among the most important (Fry et al. 2009). The first dimension considers the teaching method and the degree to which activities are more analytical or experiential; the second dimension considers the participant context and the degree to which the environment is disciplinary or interdisciplinary. Although we acknowledge that other dimensions and factors are important, for the discussion of developing innovation skills and competencies within defined curricula, we focus this paper on these two well-researched criteria of pedagogical development.

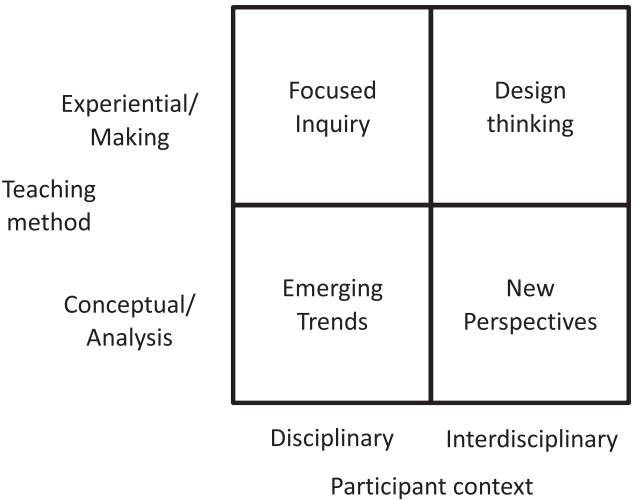
The first dimension that we consider is the degree to which the teaching method is focused on conceptual analysis or rather on experiential making-type activities. Experiential learning encompasses an active phase of learning (Kolb 1984), such as through developing actual prototypes of innovations, and design thinking courses are situated firmly in the experiential learning domain, often centered upon a semester-long product development project (e.g., Seidel and Fixson 2013). We view analytical and experiential activities on a continuum of teaching methods. On the one hand is learning through the analysis and synthesis of concepts, and on the other hand is learning through the physical act of making new artifacts,

as with the maker-movement in both industry and academia (Fixson et al. 2015, Wilczynski 2015). Both approaches result in knowledge that informs the innovator, and we will discuss this dimension in more detail later.

The second pedagogical dimension of interest represents the degree to which the participant context of the learning experience is drawn from one discipline or is interdisciplinary. Design thinking typically stresses being interdisciplinary in nature, where integration can enhance the creativity of teams seeking innovative solutions in areas ranging from business models to user experiences (Fixson 2009). In contrast, a learning context in which participants share domain expertise allows them to study subjects in depth with common understanding of a discipline. Common with other classifications (Fixson 2009), we consider the context to be interdisciplinary when participants share very little of a common curriculum, such as when business school students are mixed with engineers and designers, as has been the historical focus in interdisciplinary innovation courses.

We categorize pedagogical modes into four quadrants depending on teaching method (conceptual/analytical versus experiential/making) and student participant context (disciplinary versus interdisciplinary), whose two dimensions are given in Figure 1. To facilitate categorization and the referencing of these modes in this essay, we label the resulting four modes—emerging trends, focused inquiry, new perspectives, and design thinking—as indicated in the relevant quadrant of Figure 1. In the ensuing sections we will propose that to teach innovation effectively, students need to be exposed to all four modes across an innovation curriculum. Before doing so, we will describe the pedagogical theory behind how learning opportunities differ across the main two pedagogical dimensions.

Figure 1. Four Modes of Teaching Innovation



2.3. Teaching Method: Conceptual/Analytical vs. Experiential/Making

One theme that comes through studies of education generally and in teaching management topics specifically is that both high-order conceptual thinking and more direct engaging with complex situations, such as when making an artifact, have merit. For example, in systems thinking education, both abstracting and engaging modes have been proposed to be valuable (Cordoba-Pachon 2011). We will discuss the breadth of analytical versus experiential approaches generally and in regard to teaching the innovation process.

Bloom's (1956) taxonomy of learning describes how learning can take place at various levels of cognitive complexity: Analysis, synthesis, and evaluation constitute higher-order cognition when compared with the learning of facts. Our classification will draw upon Bloom's classification to help distinguish between teaching methods that are more conceptual or analytical versus those more experiential and making oriented. Many course syllabi are aimed at conceptual and analytical efforts, taught through such materials as academic articles and case studies. Drawing on higher-order cognition can help students to develop deeper approaches to learning, when compared with the memorization of facts (Prosser and Trigwell 1999).

A summary of primary expected learning outcomes and examples of activities using an analytical method within an innovation course are indicated in Table 1. As we note in the table, an innovation course focused on analysis might introduce the theory of the technological lifecycle and the diffusion process, and students may have the opportunity to learn how to compare the application of the lifecycle model in a range of innovations both past and present. Another learning activity may be to analyze a case of a successful design firm to discover the main elements that underlie a creative organization. A course focused on business planning may have students contrast the role of different elements of a business plan for a new innovation. Another example may be a course in

understanding customer insight through the analysis of large datasets.

Although analytical courses can have merit, they create skills only on the planning side of this dimension. As one scholar has noted, whereas planning may be helpful, it is not enough, as "there is little evidence that planning [itself] leads to success." (Honig 2004, p. 258). Although analysis and planning may help to develop high-order cognitive skills, they may be limited in other dimensions. The nature of teaching innovation lends itself to experiential learning approaches (Fixson 2009), a growing area of focus and one in which the focus is less on planning and more on action, such as in classes that develop making activities (Wilczynski 2015). In teaching design thinking, moving through the various phases from ethnographic research through to rough prototyping can be done inexpensively, lending itself to business schools that may not have dedicated workshops with major equipment or new makerspace facilities. A major theoretical treatment of such approaches is known as the Kolb Learning Cycle (Kolb 1984, Kolb and Kolb 2005). As Fry and colleagues summarize it, "Experiential learning is a continuous process and implies that we all bring to learning our own knowledge, ideas, beliefs and practices at different levels of elaboration that should in turn be amended or shaped by the experience—if we learn from it" (Fry et al. 2009, p. 15). Experiential learning allows students to confront critical events in their learning that would only come about through struggle and occasional failure in an experiential context (Cope 2005), such as making a functional prototype, and the sensemaking process when working in an ambiguous environment is supported by engaging in such activities. An experiential approach incorporates learning psychomotor skills (Simpson 1972) in addition to cognitive skills, that in innovation studies could include how to build a prototype out of cardboard or foam core.

Several academic articles have been written about various examples of experiential methods applied to teaching and learning the innovation process.

Table 1. Teaching Method, Pedagogical Basis, and Example Teaching and Learning Activities

	Conceptual/analytical focus of teaching method	Experiential/making focus of teaching method
Pedagogical basis for main learning outcomes expected	Higher-order concepts, synthesis, and analysis possible (Bloom 1956) Deeper-level learning possible (Prosser and Trigwell 1999)	Skill-based concepts (Bloom 1956) Surface-level but actionable learning (Prosser and Trigwell 1999)
Examples of teaching and learning activities in an innovation course	Comparing how dominant designs are established in different technological life cycles Analyzing a case study of a design firm to characterize innovation capabilities Describing the main elements expected in a business plan	Interpreting observations and interview data, and translating them into user needs Building a prototype to influence additional need finding in an area Conducting a patent search using online tools

Experiential education can encompass small in-class making exercises, project-based learning spanning an entire semester, and co-op placements within industry. As Lovejoy and Srinivasan (2002) described for their courses at Stanford and Michigan, they provided product prototyping facilities that allowed students to develop full prototypes of their ideas. Some universities establish student projects with industry to engage students in the real-world experience on either solving problems or suggesting new innovations (Hillon et al. 2012). Experiential education using short-term full-time placement in industry has itself had a long history, including successful cooperative (co-op) education models at universities such as Drexel and Northeastern.

More generally, a Minnesota study listed not only the advantages but also pitfalls to avoid in an experiential approach, such as poor choice of projects lacking meaningful business and design components, lack of student commitment to a full year engagement, and dominance by one school or department (Cardozo et al. 2002). We list example activities of an experiential approach in Table 1, such as interpreting observations and interview data during a design project or conducting a patent search using online tools.

2.4. Participant Context: Disciplinary vs. Interdisciplinary

Although courses on innovation can be focused on individual effort, courses for business students are increasingly centered on team projects done collaboratively (e.g., Hillon et al. 2012, Salo 2012), and the composition of team or classroom participants can have a major effect on the learning process, specifically whether membership is rooted in one discipline or is interdisciplinary.

The most common form of teaching and learning is rooted in the disciplines. Every discipline has its own broadly shared approach to teaching and learning

(Biglan 1973). For example, there may be a basic approach to introducing concepts within mechanical engineering that may be broadly shared within the discipline. The theory of discipline-specific pedagogical knowledge posits that to be an effective teacher, one cannot draw upon general learning theory but one must consider the unique elements of a specific discipline when designing courses and learning objectives for students (Berthiaume 2009).

There are important learning opportunities when all students share the same disciplinary background. First, the course can be tailored to draw upon a shared set of knowledge within the discipline for both student and teacher (Berthiaume 2009), as well as shared means of learning (Kolb and Kolb 2005). Second, a common disciplinary base allows for students to develop deeper within-discipline analyses or share more advanced disciplinary experiences than if they were to need to work across epistemological boundaries (Berthiaume 2009). As innovation itself is concerned with cumulative insights (Murray and O'Mahony 2007), this disciplinary depth can mimic some important aspects of innovation. For example, a course on research and development (R&D) management in the life sciences for chemists can allow students to understand opportunities afforded by next-generation drug discovery platforms. A summary of the main learning outcomes expected and some example outcomes for innovation courses is included in Table 2.

Evidence suggests that some of the most transformational innovations occur at the intersection of multiple disciplines rather than isolated within them, drawing from individuals with varying backgrounds, talents, and expertise (Kelley and Littman 2001, Baregheh et al. 2009). To promote innovation that spans disciplines, interdisciplinary higher education programs have become widespread, involving engineering (Shartrand et al. 2010) and business schools (Fixson 2009), with the intent of fostering

Table 2. Participant Context, Pedagogical Basis, and Example Teaching and Learning Activities

	Discipline-based participant context	Interdisciplinary participant context
Pedagogical basis for main learning outcomes expected	Learning draws from discipline-specific models (Biglan 1973) Ability to go into disciplinary depth (Berthiaume 2009) with common learning approach (Kolb and Kolb 2005)	New insight due to differing perspectives (Abercrombie 1993) Affective learning of how to work in teams (Krathwohl et al. 1973)
Examples of teaching and learning activities in an innovation course	Evaluating the real options value of an innovation, drawing from prior disciplinary work in finance Comparing drug discovery platforms for developing new compounds in a specific therapeutic area Utilizing a computer-aided-design tool to prepare a part for fabrication	Discovering how to get a diverse team on the same page of an innovation concept Conducting a brainstorm session in an interdisciplinary context Combining insights to arrive at a novel solution by using expertise in two disciplines

innovation education and aiding technology transfer. These efforts have included offering programs that integrate business, engineering, and design students into project-based teams, mimicking cross-functional teams that are ubiquitous in industry (Cooper 2001). Working well in cross-functional teams is increasingly a goal for faculty to cultivate in their students, as it can help teams to draw upon different styles of thinking or assumptions about knowledge (Boni et al. 2009).

The use of interdisciplinary teams is widespread in innovation teaching (Wang and Kleppe 2001), though best practices are still being developed (Boni et al. 2009, Thursby et al. 2009). In general, interdisciplinary teaching methods seek to harness diversity of student experiences to allow for new perspectives to emerge, to mimic real-world work scenarios (Abercrombie 1993), and to allow for affective learning (Kratzwohl et al. 1973). Courses that combine engineering, design, and business—such as at Stanford and the Massachusetts Institute of Technology (MIT)—have been successful (Fixson 2009), and drawing from different disciplines within a business school (such as across entrepreneurship, finance, and marketing) or within engineering (such as across bio-, electrical, and mechanical engineering) can be considered to also enhance the interdisciplinary nature of teams. We summarize the interdisciplinary approach and compare it to a discipline-based approach in Table 2. As we outline in this table, examples of learning outcomes in interdisciplinary innovation courses include how to communicate within a team to coordinate innovation efforts, how to brainstorm across disciplinary boundaries, and how to combine insight from

across disciplines. We next turn our attention to the four modes that uniquely combine the two pedagogical dimensions.

3. Four Modes to Teaching Innovation

Although design thinking as an approach to teaching the innovation process has received increasing attention, this approach is situated in only one of four main modes determined by the two pedagogical dimensions outlined in Figure 1. In this section we discuss all four modes to teaching innovation across these two dimensions, and we introduce them in the rough historical order in which they were prominent. We will describe the characteristics of each teaching mode and will provide example courses, as outlined in Table 3, which will help to demonstrate the strengths and limitations of each mode.

3.1. Analytical-Disciplinary: “Emerging Trends”

The analytical-disciplinary model of learning is our starting point, a mode we label as emerging trends, one that is rooted in the disciplinary focus that has been the standard model in universities (Abbott 2001). In business schools, teaching the innovation process grew out of traditions within disciplines such as economics, the history of technology, and sociology (e.g., Schumpeter 1942, Sahal 1981, Rosenberg 1982), and it draws upon a research tradition informed by operations and technology management within schools of business and schools of engineering (e.g., Abernathy and Utterback 1978, Abernathy and Clark 1985, Tushman and Anderson 1986, Henderson and Clark 1990). The majority of courses from this tradition employed teaching cases.

Table 3. Characteristics of Innovation Courses Using Each Teaching Mode

Teaching mode and characteristics	Typical course focus (and example title)	Typical innovation focus	Project realism	Institutional complexity	Resources: materials and faculty time	Outcome uncertainty
Emerging trends • Conceptual/analytical • Disciplinary	New technology (e.g., “Innovation and entrepreneurial growth” at Northeastern University)	Radical	Low	Low	Low	Low
New perspectives • Conceptual/analytical • Interdisciplinary	Innovation management (e.g., “Strategy & Innovation” at Oxford University)	Radical	Medium	High	Low	Medium
Focused inquiry • Experiential/making • Disciplinary	Product development (e.g., product design courses at Babson College and at Singapore Management University)	Incremental	Medium	Low	High	Medium
Design thinking • Experiential/making • Interdisciplinary	Design process (e.g., “Integrated Product Development” at Delft University of Technology)	Incremental	High	High	High	High

Note. Titles are of courses discussed in the text.

An example of an analytical-disciplinary emerging trends course is one titled “Innovation and Entrepreneurial Growth” at Northeastern University. This graduate-level course covers the innovation process, R&D commercialization, and the details of new technologies. The course has used technology experts as guest speakers, case studies, and videos to expose students to the latest in emerging technologies and implications for commercialization. The main course deliverable has been a project focused on an emerging technology, including the technology, barriers to entry, intellectual property, and potential applications. The students are encouraged to explore technology in detail, but not be constrained by current limiting factors of technology commercialization and the economic context. Another example, this time from Asia, is the Singapore National University course “Creating, Capturing, and Delivering Value with Technology,” where the emphasis is on the development and application of conceptual models related to innovation and market evolution rather than experiential learning.

Such emerging trends courses provide several benefits (as summarized in Table 3). They allow students to explore in-depth a technology that may have little current commercial value yet may lead to radical innovations in the future. As such courses are centered in a shared discipline, students can go into more depth of analysis together than otherwise possible. As it is focused on analysis without the need for actual technological prototyping, the resources required to run such a course are modest, and the ability to complete the project is high. There are limits too, mainly centered on project realism. Although an analytical-disciplinary mode may seem outdated, from understanding the history of technology to the means to analyze a disruptive technology, an emerging trends mode allows students to think deeply about the innovation process free from current constraints.

3.2. Analytical-Interdisciplinary: “New Perspectives”

The development of analytical-interdisciplinary courses features often in curricula combining business and engineering programs, a mode we will label new perspectives, as seen in programs such as the technology management program at the University of Pennsylvania. Not only these curricula but also individual courses were designed to combine business and engineering perspectives in one setting. And although industry projects factored into innovation-related courses within such programs, large sponsor organizations often focused on analysis and planning over applied outcomes.

Analytical-interdisciplinary courses can be tailored to study radical technology, not unlike the emerging

trends mode, but in a broader manner that adds other viewpoints and expertise. For example, a lesson in sustainability can include the perspective not only of business school students but also of biologists, engineers, and chemists. As an example, the interdisciplinary graduate course at Oxford University, “Strategy & Innovation,” has extended the student reach of a master of business administration (MBA) course to include doctoral student scientists and engineers. The course has primarily focused on developing a set of analytical concepts and tools that enable students to assess new areas of opportunity in new innovative domains. For example, students might use course concepts to analyze the emergent area of quantum-based computing, developing strategic recommendations for those organizations that might want to take advantage of this area. Non-MBA students have included doctoral students in biological composites, orthopedic biomechanics, optical microscopy, and semiconductor physics.

The benefits of analytical-interdisciplinary courses are that they can easily focus on radical innovations, and with the added realism of alternative expertise and knowledge, they can be important to understanding innovation from multiple perspectives. As outlined in Table 3, this mode can lead to more realistic analyses than those of emerging trends, but they come at a cost of higher institutional complexity due to such simple factors as how credits get counted across disciplinary boundaries, and possibly even school boundaries. The uncertainty of any multidisciplinary project is qualitatively higher than those that are drawn from students sharing a discipline; for example, students may disagree on what processes to follow, as has been seen in studies of design teams (Seidel and Fixson 2013). Given diversity of background and prior training, some student teams may have real challenges in completing their task on time to a satisfactory level when compared with single-discipline teams.

3.3. Experiential-Disciplinary: “Focused Inquiry”

The development of offerings in the third category, experiential-disciplinary, is a combination we label focused inquiry. A disciplinary focus came about as business schools responded to two influential reports of the 1950s—the Gordon-Howell report commissioned by the Ford Foundation (Gordon and Howell 1959) and the Pierson report sponsored by the Carnegie Foundation (Pierson 1959)—that had accused them of teaching unsubstantiated descriptive content (Pfeffer and Fong 2002); in doing so, they broadly developed into schools applying social science methods grounded in the discipline. Later, under critique from several management scholars (e.g., Mintzberg 1992), many schools have introduced

a more experiential and action-learning approach into their curricula (Dutson et al. 1997, Hillon, et al. 2012), leading to a combination of experiential action and disciplinary focus.

An example of a highly experiential course is an MBA course on “Product Design and Development” at Babson College. The learning context is disciplinary, as all students are enrolled in a business program, although their undergraduate education varies. In this project-based course, student teams experience the design process, including problem finding, user research, alternative concept generation, and prototype building, and testing. Product design projects serve as the vehicle for the students to experience, iterate, and learn from going through an innovation process. Another example is found in an MBA course run at Singapore Management University in which business students learn how to develop simple prototypes to meet the needs of clients or as part of student-initiated opportunities.

As with the other teaching modes, there are benefits and limits to this mode. By involving students in vetting their propositions, such as through building and testing prototypes, this approach leads to more grounded, yet incremental, project results. As we outline in Table 3, the institutional complexity is lower than those that have interdisciplinary teams, but there are higher material costs, and the need to help students respond to technical and market feedback puts more demand on faculty than in purely analytical courses. Students are driven to schedules that are not under their own control when compared with a purely analytical course, and this can be a source of frustration, but the outcome is a product that has a high degree of realism from which practical lessons will have been learned.

3.4. Experiential Interdisciplinary: “Design Thinking”

Finally, the fourth mode combines experiential teaching and an interdisciplinary context, which is the basis of the design thinking model advocated by many for teaching innovation in business schools (Glen et al. 2014). Although design thinking is not defined solely by being experiential and interdisciplinary, these are two fundamental dimensions of this user-focused mode.

On some level, offerings in this category are a response to the accelerating dynamics underlying the separate developments that led to the interdisciplinary and experiential categories. For example, many business schools are increasingly recognizing that the high levels of uncertainty typically associated with innovative endeavors are difficult to teach without having students simultaneously directly experiencing the associated emotional and intellectual challenges (Fixson and Rao 2011, Fixson and Rao 2014). Approaches to

problem solving familiar to designers appear to be particularly promising in addressing this issue (Fixson and Read 2012, Garbuio et al. 2017). Similarly, the National Academy of Engineering, an advisor to the United States government on engineering and a representative of the academic engineering community, has recently described what it expects the attributes of engineers to be at the end of the second decade of the 21st century. In addition to the traditional engineering attributes of strong analytical skills, they expect the future engineer to exhibit practical ingenuity, creativity, good communication skills, as well as leadership, professional ethics, and an ability for lifelong learning (National Academy of Engineering 2004). A sample of courses representing this experiential-interdisciplinary mode that incorporate business, engineering, and industrial design can be found in Fixson (2009), who reports on more than a dozen courses and three programs that integrate all three disciplines.

As an example of this mode, Delft University of Technology, located in the Netherlands, has developed a master’s program dedicated to product design in which they are pushing interdisciplinary education to what they term a “transdisciplinary” model. The university’s integrated product design program combines advanced studies in innovative design theory and methods, aesthetics, ergonomics, engineering, and sustainability. Experiential learning is a feature of the program, with students from across disciplines working on multidisciplinary projects for established firms and also completely new ventures.

There are both benefits and limits to experiential-interdisciplinary collaboration (as summarized in Table 3). Experiential innovation during semester-long product development courses by necessity leads to simpler, incremental innovations, in order to fit within course constraints on time and materials. Experiential-interdisciplinary courses have the highest uncertainty as to whether the teams create an outcome of value, due to the complexity in working within interdisciplinary teams and the feedback they gain from testing their ideas in both technological and market dimensions. These courses can be considerably more costly to run than the other forms profiled, both in terms of material cost and faculty time. A course at Stanford, for example, estimated that a course cost about \$400 per student in materials, and the instructors expect that it took about 50% more teaching time to run this course than other courses (Lovejoy and Srinivasan 2002).

Experiential-interdisciplinary courses have been at the forefront of innovation instruction for the last decade or so. They can help students learn important project management, team collaboration, and leadership skills. Unfortunately, these courses

are expensive, difficult to teach, and may be most appropriate to only a subset of more incremental innovations.

4. Implications for Curriculum Design

In the past decade, literature on innovation courses has focused on the growth of opportunities for experiential learning (Fixson 2009) and opportunities to adopt design thinking as an approach within business schools (Dunne and Martin 2006, Glen et al. 2014) and in society more generally (Brown 2008). In our assessment across two important pedagogical dimensions we instead propose a plurality of modes to be used. To effectively teach the innovation process that encompasses both incremental and radical innovation outcomes, students need to be exposed across the range of two teaching methods: (1) highly experiential development projects that best focus on incremental innovation and project management and (2) highly analytical courses that best focus on emerging technologies and opportunity assessment, which help drive understanding of radical innovations.

We also argue that a second dimension, the participant context, helps us to consider two ways that can each have value: (1) a disciplinary context where there is a common language and the opportunity to go into depth and (2) an interdisciplinary context where multiple perspectives can be brought to bear on a domain. Taking the two dimensions together, we believe that a portfolio of all four modes of innovation teaching has merit in a curriculum focused on the innovation process.

Although there has been a recent focus on teaching user-centered innovation by way of experiential courses using design thinking (e.g. Glen, et al. 2014), including those that involve teams from across disciplines (Fixson 2009), we propose such courses are but one component of a comprehensive curriculum. There are many terms to capture the notion of depth and breadth, but a common recent metaphor is that of the T-shaped individual who has a breadth of understanding coupled with a depth of disciplinary knowledge. At the design firm IDEO, these individuals were called “cross-pollinators” (Kelley and Littman 2001). The four modes we describe provide one way to encourage individuals to learn the innovation process in a way that appropriately combines breadth and depth.

Whereas we described the four modes in a sequence, it is an open empirical question as to whether it is best to engage students in a specific order through these modes. We do believe it is most beneficial for students to have exposure to each mode. Some schools may be able to offer courses that each work within a mode. Others may choose to alternate in a more dynamic fashion, spiraling through each area, perhaps

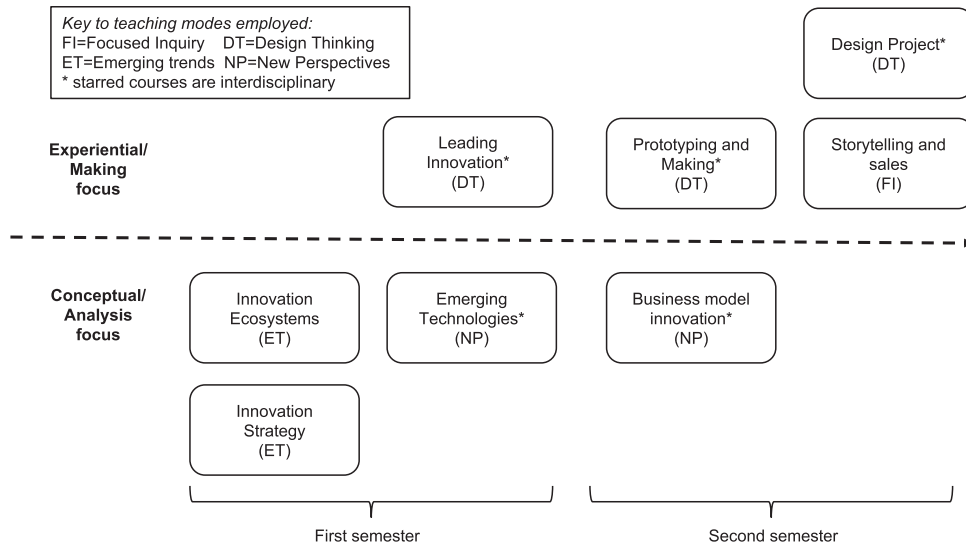
even during a single course offering. This is not unlike spiral development in software, which quickly rotates focus from planning and analysis, to resolution, to development and testing (Boehm 1988).

The objectives of an innovation curriculum may dictate focus on one mode over another. In designing a new curriculum on the innovation process, are university spin-outs desired? If so, this may enhance the importance of more experiential, interdisciplinary projects that are closer to market, and may require real-world mentors and resources. For those programs that center on corporate involvement and a focus on long-range technology, analytical methods may factor more strongly. We recognize it may be a challenge to do all modes well in the same program, and they may not need to be done equally. Courses and curricula are established with certain objectives, whether program-level ones such as the number of start-ups to target, or learning objectives at a course level. Constraints such as course length, ability to provide makerspace facilities, and the training of instructors also factor into what variety of courses can be achieved. The sum of these institutional factors may tip a balance in favor of different courses in a curriculum, but at a curricular level, we believe engaging across these modes will help students to truly learn a range of fundamental aspects of the innovation process.

4.1. Example Curriculum Across the Four Modes

As mentioned earlier, an institution’s objectives will dictate the design of a full innovation curriculum. For example, some institutions may wish to emphasize more practical outcomes, whereas others are more interested in “blue sky” innovations. Recognizing that there is no single curriculum that should be the standard for all institutions, we use one illustrative curriculum, outlined in Figure 2, to describe how courses can range in how they span the four modes. This example curriculum is envisioned for a one-year graduate program in innovation studies, drawing students from a range of backgrounds including business and engineering. In this example curriculum, students are exposed to eight courses spanning all four teaching modes across the two dimensions. In our figure, the conceptual/analytical versus experiential/making dimension runs vertically; the disciplinary versus interdisciplinary dimension is signified by an asterisk noting those that are interdisciplinary; and a key provides a description of how these dimensions map teaching modes onto each course.

This illustrative graduate curriculum uses a quartile system across two semesters. In the first quartile of the first semester, students would be immersed in conceptual analysis of innovation trends, through studying innovation ecosystems and innovation strategy tools and methods, both falling in the emerging

Figure 2. Illustrative Example Graduate Curriculum of Eight Courses, Drawing from All Four Modes of Teaching Innovation

trends mode of teaching. In the second quartile, they would take their first experiential course, learning tools and techniques on leading innovation, in part by forming teams and engaging in experiential exercises. At the beginning of the second semester, the students would have two interdisciplinary courses, one analytical (business model innovation) and the other experiential (prototyping and making). In the final quartile, students would complete a comprehensive, interdisciplinary design project, alongside a focused, experiential class on effective storytelling, sales, and business development. Although we have only painted a broad-brush of what these courses would cover, the idea is that under such a curriculum, students move back and forth between analytical and experiential courses and mix deep disciplinary investigation with interdisciplinary experiences. In our example, there is a slight weighting toward courses that employ a design thinking mode (experiential interdisciplinary), but all four modes are represented at points in the year.

The intent of this essay has been to provide a framework to describe the modes that may be employed when teaching and learning the innovation process, providing some balance to a pedagogically narrow focus on one mode at the expense of all others. No single mode addresses every opportunity for learning the innovation process, and each comes with advantages and limitations. For example, an emerging trends mode may help students gain in-depth understanding of opportunities for radical innovations, but at the expense of project realism. Conceptual emerging trends courses are important because they serve to identify pathways to radical innovation that one may not have exposure to experientially. A design thinking mode will offer high project realism, but at the expense

of institutional complexity and outcome uncertainty. Combined across a curriculum, the range of modes may facilitate the development of individuals who are better able to develop both breadth of experience and depth of understanding of topics important for careers in which innovation may play a central role. At the same time, even though our framework lays out course archetypes, some courses may straddle modes, such as those that incorporate in-depth conceptual analysis of cases at one point in the semester and use a makerspace to prototype designs later in the semester.

In developing new curricula, it can be powerful to use projects that could span and connect different courses and teaching modes, showing the power of their use collectively and how the lessons learned in each mode can be applied to an innovation project. Ultimately, this can illustrate the complexities of innovation in large-scale projects, as well as how the most interesting innovations are combinations of both incremental and radical advances. For example, ride-sharing applications are certainly a transformative business model, even if not based on radically new underlying technologies. Drawing from insights from a range of courses and their associated teaching modes may lead to projects that combine innovations across products, services, and new business models.

4.2. Reflections on Teaching Across These Modes

In our own teaching, we have some reflections to share that build on the themes we have developed. A first reflection has to do with how one may need to go outside one's own campus to best meet the needs of one's students. As an example from our experiences, Northeastern University has provided an experiential-interdisciplinary course that partners its business students with design students at the Massachusetts

College of Art and Design. Several class periods are devoted to brainstorming techniques, ethnographic investigation, and exploring opportunity spaces designed to expose students with engineering backgrounds to divergent thinking (Marion et al. 2012). The main deliverable in the class is a semester-long capstone-like project. A key differentiator is the ability of the teams, with a fixed budget, to go outside the team and school to hire resources, which can include engineers and software developers. Final project deliverables include look-and-feel prototypes, functional prototypes, and a bill-of-materials generated from outside quotes (Marion et al. 2012). Although the coordination of this type of course is complex, the interdisciplinary nature adds new perspectives for the students as they work on the design of an actual product.

Considering our experience with such courses, the incremental focus of many experiential courses often occurs because it requires a validated product concept at the end, and has budgetary and time constraints. In contrast, classes focused on analysis typically allow for unconstrained exploration of an innovation topic, which is often an emergent and exciting technology. On reflection, one way we consider promising for pushing the boundary of the experimental/making dimension for exploring more radical innovations is through simulations. We have recently been experimenting with incorporating simulations as a new means of experiential engagement in the classroom because simulations allow students to engage in the experiential learning cycle without the same material expense or time constraints. For example, two of us recently developed a web-based simulation (which can be used from distributed locations or in the classroom) that puts students in the shoes of an employee in charge of an innovation project. In the simulation, the task is to choose between different innovation process options, varying the size, diversity, and expertise level of the contributor population, as well as manipulating incentives. Reflecting the stochastic nature of the innovation process, the outcomes are probabilistically determined, and provide a learning experience that connects process choices to the radicalness of the outcome. Although this was our first attempt to develop simulations, we feel the use of simulation may be one that will see further expansion as part of the making toolkit in teaching innovation.

5. Conclusion

One prominent perspective on curriculum design in higher education advocates that you cannot overly plan a curriculum in advance; rather, one should manage the process of how a curriculum is developed through the efforts of many teachers (Knight 2001). We would agree that not every element of the curriculum can be designed in advance; however, like

other approaches to teaching business students that highlight a range of methods (cf. Cordoba-Pachon 2011), we advocate understanding different modes of teaching that can serve distinct purposes. Guiding the process of curriculum development for teaching the innovation process is the realization that all four modes of innovation teaching are important, and any curriculum design process for educating innovators should be sure to consider all four. Conceptual/analytical and experiential/making methods, as well as disciplinary and interdisciplinary contexts, all have a role to play, even if the precise nature of the courses will be subject to the design of individual instructors. To create the next generation of innovators, we believe developing the learning opportunities promoted by all four modes will be essential.

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