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Integrating the Engineering Curriculum through the Synthesis and Design Studio

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ABSTRACT

Traditional curricular approaches within engineering education tend to be fragmented, with opportunities for content- and meta-level synthesis being mostly limited to freshman and senior year design courses. In this paper, we are proposing a curricular model, the Synthesis and Design Studio, to combat the tendency towards fragmented curricula. The approach proposed here attempts to negotiate the realities of fragmented curricula by providing an integrative learning component that exposes Environmental Engineering students to open-ended projects with the intent that students will develop an integrated understanding of their courses, lives, and professional futures. The pedagogical features and theoretical design of the Studios will be described. Project-led research was conducted, and results from this interpretive analysis of reflections and focus group transcripts are described to explore students' accounts of both content- and meta-level integration as they participated in a Studio.

Keywords: integrated curricula, trans-disciplinary, studio

INTRODUCTION

Educating creative and innovative engineers is widely recognized as critical in solving the current and future challenges facing society (ASCE 2004; ASEE 1994; Fortenberry 2006; Journal of

Engineering Education 2006; National Academy of Engineering 2004; Spinks, Silburn, and Birchall 2006; Friedman 2005; Duderstadt 2008). In this world of complex and highly interconnected problems (National Science Board 2007), it is critical that every engineering student graduate with a well-rounded education that includes abilities ranging from engaging in complex thought, analysis, quantitative, and qualitative reasoning to communicating effectively (Felder et al. 2000; Wulf and Fischer 2002; National Academy of Engineering 2004, 2005; National Academy of Sciences 2007; ABET 2004).

Part of achieving the aspirational goals of engineering education set out by the Accreditation Board for Engineering and Technology (ABET 2004) is to provide breadth to undergraduate education. Unfortunately, in its implementation, this drive for breadth has often led to a general education curriculum with a set of disparate and unconnected courses, instead of an integrated experience (Olds and Miller 2004; Beane 1995). This is fundamentally at odds with the interconnected nature of the knowledge future engineers require in order to be creative and innovative in approaching the above-mentioned challenges (Charyton and Merrill 2009). In the Greater Expectations report, the Association of American Colleges and Universities recognizes the “fragmentation of the curriculum” as a significant “barrier to high quality” (2002). Similarly, the Boyer Commission on Educating Undergraduates in the Research University explains that “the freshman experience needs to be an intellectually integrated one, so that the student will not learn to think of the academic program as a set of disparate and unconnected requirements” (1998, 19).

As a possible avenue for overcoming this fragmentation of engineering students’ learning, we present and discuss a curriculum integration initiative at the University of Georgia within the Environmental Engineering undergraduate program. This curriculum integration initiative addresses integration at both a content level (integration of content across courses) and a meta-level (integration of meta-learning and ways of thinking). More specifically, we describe the design and implementation of a Synthesis and Design Studio Series that is threaded throughout the four years of the program and, in a qualitative research component, analyze students’ accounts of integration while participating in the Studio. The description of the initiative comprises the overall series of Synthesis and Design Studios (Seminar Studio, Studio I, and Studio II) that culminates in a trans-disciplinary course with engineering and art students in the third year of the series (Studio III). In this description, Studio II is used as a representative example to illustrate the learning content and activities of all courses of the series.

CONCEPTUAL FRAMEWORK AND BACKGROUND

The following provides the conceptual framework for our curricular model and locates the departure point of this work in the current discourse within the engineering education community.

To this end, we summarize prior work on the role of creativity and interdisciplinarity in curriculum integration of meta-learning, and discuss existing efforts and approaches to integrate content and curricula in the engineering context.

Meta-Level Integrative Learning through Creativity and Interdisciplinarity

The role and importance of reflection in students' professional (Dall'Alba and Sandberg 2006; Schoen 1987) and intellectual (Felder and Brent 2004; Perry 1970) development has been widely explored, both in the area of experiential learning in general (Dewey 1933; Kolb 1984) and in the field of engineering education in particular (Canale and Duwart 1996; Jiusto and DiBiasio 2006; Wankat and Oreovicz 2001). Due to the importance of reflection in student professional and intellectual development, we have included a meta-level integrative learning component within the curricular model described in this paper. Reflection is included in this curricular model through many different modalities, including both verbal and visual modalities such as focus groups, visual journals, and arts-based learning activities. Creativity and interdisciplinarity are central to this meta-level integration and are described in more detail below.

Creativity is an inherently integrated, cross-disciplinary process, as elaborated by Robert and Michelle Root-Bernstein (1999). These creativity researchers stress the importance of fundamental thinking tools as being the essence of the creative thought that is common across disciplines with different ways of expressing their thinking:

> *Moreover, at the level of creative process, where it really counts, the intuitive tools for thinking that tie one discipline to another are entirely ignored. Mathematicians are supposed to think only "in mathematics," writers only "in words," musicians only "in notes," and so forth. Our schools and universities insist on cooking with only half the necessary ingredients. By half-understanding the nature of thinking, teachers only half-understand how to teach, and students only half-understand how to learn. (1999, 12)*

Deliberately engaging students in creative thinking processes is thus critical to their development as innovative thinkers who are able to work across multiple knowledge domains. This meta-level integration of disciplines can help students understand the universality of creative thinking processes as demonstrated, for example, by Cunliffe's (2008) investigation of the use of interdisciplinary curriculum to foster creativity in extra curricular activities in secondary schools.

Based on these findings from prior work, we contend that fostering creativity in interdisciplinary experiences is a way to integrate curricula at a meta-level. An interdisciplinary experience involves using methods from multiple disciplines to develop an understanding of a problem or topic (Beane

1997, 1995; Jacobs 1989). The Studios described later in this paper range from reflective experiences in which environmental engineering students explore interdisciplinary ways of thinking to these students engaging in a trans-disciplinary studio that includes art students in joint projects. For illustrative purposes, we will describe one of the Studios offered to date in a later section to demonstrate ways that we attempted to provide an integrative engineering curriculum at a meta-level through creativity and interdisciplinary ways of thinking.

Content-Level Integrative Learning in Engineering

In response to the need for a more cohesive curriculum, content-level integrated learning opportunities have been implemented in many engineering programs (Olds and Miller 2004; Bordogna, Fromm, and Ernst 1993; Froyd and Ohland 2005). Indicative of this development are efforts to integrate student learning in engineering through capstone Senior Design experiences and, more recently, through freshman engineering courses (Froyd and Ohland 2005) as well as through spiral curriculum approaches (Lohani et al. 2011). These approaches have moved us closer to the goal of an integrated curriculum at the content level. The bookend approach, with a freshman engineering course at the beginning and a capstone experience at the end, provides students with an opportunity to integrate their learning both early and late in the program (Froyd and Ohland 2005). A spiral approach provides continuous integrative elements, but also requires more systemic redesign of the entire curriculum (Bruner 1960). These approaches provide the engineering curriculum with varying levels of content-level integration.

The curriculum integration efforts described above have uniquely positioned engineering education as a discipline to lead the development of content-level integrative approaches to student learning at a time when other professional disciplines are adopting similar strategies to create integrative capstone courses and experiences (Huber 2006). However, both approaches can have limitations or be subject to institutional constraints. We propose that an ongoing content- and meta-level integration of curriculum can be achieved within the institutional constraints of existing programs and simultaneously provide students with a cohesive overall learning experience. The Studio model presented in the following sections provides students with a continuous integrative experience that can draw together their learning from other courses with prior, current, and new life experiences.

Methodological Position of This Work

To facilitate the understanding of the work presented here, the following explicitly defines our methodological position for the curricular design approach as well as for the qualitative research component presented.

This initiative was based on emergent, contextual design informed by existing research and the scholarship of teaching and learning. As such, we rejected systematic experimental approaches to curriculum design for pragmatic as well as ethical reasons. More specifically, we designed the Studio model for the particular context of both the program and the institution to achieve the best possible outcomes for all students in a continuous improvement process rather than through a control group design. Analogous to this curriculum design approach, our research into the initiative emphasized an understanding of the particular context and the development of transferable insights into the nature of integrative learning over the generalizability of a universal curricular approach. While perhaps unconventional in the engineering education context, this approach rests on the tradition of curriculum development and educational research that Borrego and Bernhard (2011), in the recent centennial edition of the *Journal of Engineering Education,* termed "problem-led" research, as opposed to "method-led" research.

This paper thus presents the curricular model as it emerged from the particular institutional context and followed an innovative pathway towards curriculum integration at both a content and meta-level. The presentation emphasizes the conceptual underpinnings of the design. In the qualitative study of the impacts on student learning, these concepts are connected to and illustrated through an authentic representation of the students' shared lived experiences of the Studio. On the basis of this connection of concepts and their manifestation in students' experiences, we derive a number of insights that can provide an illuminating perspective on similar endeavors that are undertaken in similarly unique contexts.

STUDIOS: A CURRICULAR INNOVATION TO ACHIEVE PROCESS- AND META-LEVEL INTEGRATION

The following describes the institutional context in which the curriculum innovation took place, outlines the conceptual model, and presents concrete pedagogical features of the Studio Series. A subsequent section introduces a view on the curriculum design process to shed light on the thought processes underpinning this initiative.

Context: Curriculum Development within Existing Structures

The developments at the University of Georgia were based on the outcomes of the Engineering Think Tank, with interdisciplinary members from visual arts, cellular biology, pharmacy, geography, and engineering. In a series of interdisciplinary focus groups with undergraduate students, graduate students, faculty members, and administrators the Think Tank first developed the profile of a graduating engineer, and then the environmental engineering curriculum committee was charged with devising a curricular model for attaining this type of student. Through these focus groups, the Think Tank developed the resulting profile of a graduating engineer as an engineer who is technically excellent, humanistic, and innovative. Achieving students' technical excellence leveraged the strength of existing traditional program structures. The Think Tank report specified the following three components of an innovative engineer: one that engages in lifelong learning, is creative, and can adapt in a changing, complex world. Being humanistic is conceptualized as critical in facing global issues that require engineers to be embedded in the human and environmental contexts of their work. The Think Tank also developed a vision for engineering at the University of Georgia as "Engineering in a Liberal Arts Environment." To implement this vision, the university began admitting students into the Environmental Engineering curriculum in Fall 2007, and is currently transitioning to the Environmental Engineering curriculum as envisioned by the curriculum committee that is intended to overcome engineering students' commonly observed difficulties in developing innovative and humanistic designs for local complex systems.

The design and implementation of the Studio Series was situated within the context of existing engineering fundamentals courses from established engineering majors. While these constraints did not allow for a clean-slate curriculum design, significant flexibility to implement novel curricular structures was afforded by the new program. With these constraints and the goal of the technically excellent, humanistic, and innovative engineer in mind, the design of the Environmental Engineering curriculum was guided by the following questions: How can we improve the undergraduate learning experience through efforts to integrate the curriculum across the seemingly disparate departmental and engineering course content silos? More importantly, how can we encourage integration within the learners themselves? To reach the goal of a fully integrated learning experience, we proposed a continuous integrative approach to engineering education—one that actively encourages the individual learner to integrate their learning across engineering content and within themselves through a more immersed approach.

Proposed Curriculum Integration Model

Curriculum integration occurs at different levels and intensities in an educational program. The lowest level involves integration within one discipline (content-level integration), the next involves integration across several disciplines (content-level integration) and the highest level involves integration within the learners themselves (meta-level integration) (Fogarty 1991). The lowest level implies a fragmented curricular approach, which involves separate courses that rarely make explicit connections between courses. This is the case in most engineering fundamentals courses, with only an implied connection to other courses through prerequisites and co-requisites. At the other end of the spectrum, the ideal of a fully integrated curriculum synthesizes engineering and non-engineering content as well as the students' prior, current, and new life experiences and thinking processes, such as creativity and lifelong learning. This reflects current knowledge about how people learn, highlighting the importance of connecting academic knowledge to real-life experiences (National Research Council 2000).

We propose that a high-level integration of the curriculum (Clark 1997) involves integration across courses at a content-level as well as integration of multiple aspects of the learner at a meta-level. This integration is represented metaphorically as a binding or spiral connecting the tabs of a notebook (see Figure 2) that symbolize the curriculum as well as students' current, prior, and new life experiences, factors that in combination contribute to students' overall learning (Bransford, Brown, and Cocking 2000). The spiral also signifies a connecting and integrating element along the dimension of the curriculum, thus overall representing integration at both a content- and a meta-level.

The Studio Approach

The background sections discussed existing models of curriculum integration in engineering and outlined the contextual constraints of achieving integration while leveraging the existing curricular structures of the particular institution. Building on this prior work and accounting for the contextual conditions, the Environmental Engineering curriculum committee developed and adopted a Studio approach in an effort to integrate the curriculum at both a content- and meta-level. The following describes a number of characteristics of the Studio approach as set out in the broader literature.

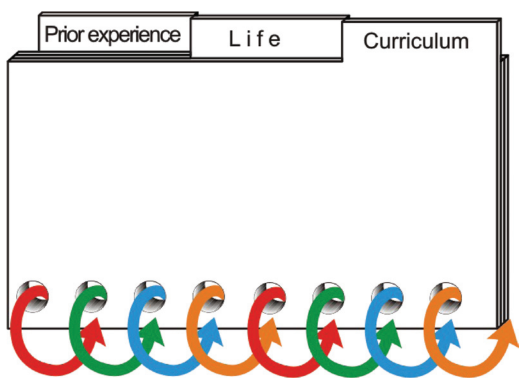

Figure 1. Representation of holistic student development through the concurrent, meta-level integration of the curriculum and content-level integration of courses (spirals of the notebook) with prior, current, and new life experiences (tabs of the notebook)

The studio approach is adopted from Rieber's graduate-level studios within Instructional Technology at the University of Georgia (Orey et al. 2000; Rieber 2000). These instructional technology studios were designed around the following ideas: 1) learning is active and is constructed by the learners, 2) learning is inherently situated and social, and 3) learning involves designing, developing, sharing, and critiquing artifacts. The Studios proposed in this paper create a community of practice (Lave and Wenger 1991) for students and instructors to collaboratively learn by engaging in broad, socially-situated engineering challenges.

Through this studio approach, the intention is for graduates of this program to have developed an engineering disposition. According to Perkins et al., *disposition* includes abilities, the inclination to use these abilities, and sensitivity to appropriate opportunities to use these abilities (Perkins, Jay, and Tishman 1993; Tishman, Jay, and Perkins 1993). Through engaging in a studio approach, it is our intention for our students to become innovative, humanistic, and technically excellent, while developing an engineering disposition in which students graduate with, not simply a range of abilities, but an inclination to use them and a keen eye to find opportunities to use these skills appropriately.

The Synthesis and Design Studio Series to Integrate the Engineering Curriculum

The Synthesis and Design Studio series is the curricular structure that emerged from these considerations to concurrently integrate the Environmental Engineering curriculum at both a content- and a meta-level. The Studio Series is threaded throughout four years of the Environmental Engineering curriculum, with one trans-disciplinary Studio in the third year. In Figure 2, the spiral-bound notebook representation has been modified to represent the Environmental Engineering integrative student experience based on existing curricular structures. In this figure, the engineering curriculum is represented by the top page and tab of the notebook. The curriculum is subdivided into fundamentals, a humanities core, and integration courses. The Environmental Engineering curriculum was envisioned in this way, and consists of 53 credit hours within the fundamentals, including science, mathematics, and environmental engineering courses, 24 credit hours within the humanities core consisting of social sciences, liberal arts, and languages, and 39 credit hours of integration courses consisting of systems modeling and analysis, energy and mass, infrastructure and planning, and economics. The Synthesis and Design Studio consists of 14 credit hours occurring throughout the four years. This combination of single-subject courses and integration courses is a way to integrate the curriculum that does not involve a complete revision of the current higher education curricular structure. This approach is critical in that it stresses that an integrated curriculum is not an all or nothing change; it can also be a combination of curricular elements that helps to achieve an integrated curriculum (Jacobs 1989, 19).

The main objective of the Synthesis and Design Studio is for students to develop a deep understanding of the larger socio-technical systems in which engineering is situated. Throughout the

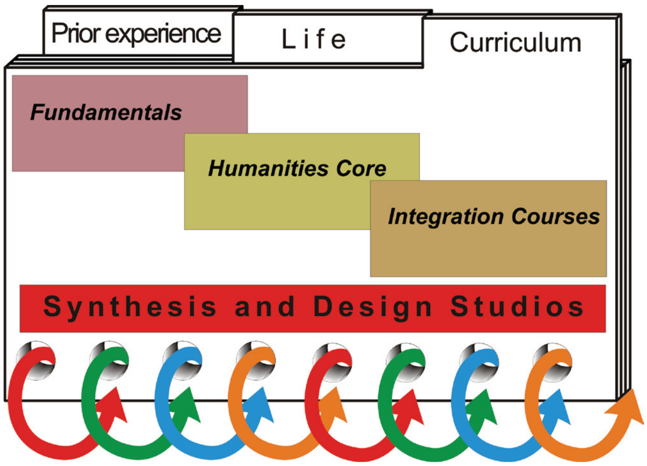

Figure 2: Representation of holistic student development through the concurrent integration (spirals of the notebook) of the curriculum with prior, current, and new life experiences (tabs of the notebook); the curriculum contains fundamentals, humanities, and integration courses, and is integrated through the Synthesis and Design Studios

four years, students will develop an understanding of the interrelationships between engineering, the social sciences, and the humanities. Our premise is that, as a result of the Studio Series, the students will become systems thinkers with the ability to think holistically as well as reductively in order to be prepared to deal with the complex issues that they will face in their careers. The Studios will thus provide a curricular integration at both a meta-level and a content level. The Studios meet simultaneously to encourage near-peer learning and mentoring among the students; for example, sophomores will provide mentoring to freshmen. These peer mentoring aspects of the studio are modeled after the graduate-level studio courses that have been implemented in the Educational Psychology and Information Technology department at the University of Georgia over the last 10 years (Orey et al. 2000; Rieber 2000).

In each year, Environmental Engineering students are required to enroll in a Synthesis and Design Studio with a focus on observation, modeling, project management, communication, and problem framing, and with a strong focus throughout on synthesis and design, as the name implies. As illustrated in Figure 3, the Studio approach focuses on integrating the traditional fragmented curricular elements (content-level integration) in order to support students' holistic development, including their creative problem solving and design skills (meta-level integration). The integrative Studios (represented by the flower pot in the central part of Figure 3) are the means by which we have integrated the traditional curricular structures (general education courses, fundamental engineering science courses, and

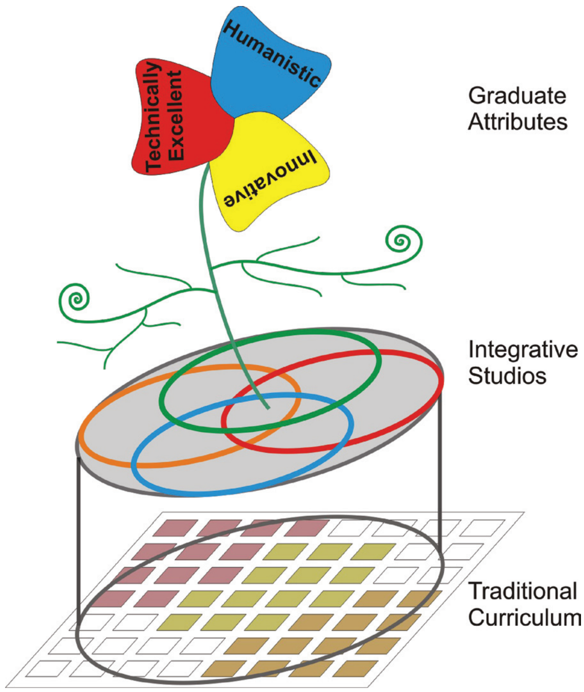

Figure 3: Concurrent curriculum integration through Synthesis and Design Studios

engineering electives; these are represented by the lower plane in Figure 3) to achieve the desired graduate attributes of being technically excellent, humanistic, and innovative (represented by the flower in Figure 3). This is our model for integrating the Environmental Engineering curriculum.

The Engineering Synthesis and Design Studios are currently in their sixth iteration, with the first initiated in Fall 2009. The Studios use a project-based learning approach (Markham, Larmer, and Ravitz 2003) and meet for six hours per week, with two credit hours earned per semester (with the exception of the seminar studio that occurs during the first semester of the freshmen year and meets for one hour per week with one credit hour earned). Much of the work in the course is completed during the time in the studio, as is common in art studios (Hetland et al. 2007). The broader goals of the Studios are on developing students' observation and modeling skills, management and communication skills, problem framing skills, and synthesis skills through experiencing engineering design challenges focused on sustainability. Students are required to keep a visual journal, to participate in reflective focus groups (Walther et al. 2009), to write a process reflection report, and to submit a range of deliverables for each project.

The Synthesis and Design Studio Series consists of annual studio sessions that provide students with an environment that actively encourages them to establish synergies among their engineering courses, between their engineering courses and humanities or social science courses, among their thinking processes, and between their education and their life outside the university (see Figures 1 and 2). The fundamentals of the curriculum are unchanged from those of typical and traditional curricula with science, math, engineering sciences, humanities, social sciences, and engineering electives. Through experiencing the Studios while engaging in fundamental courses, the humanities core, and integration courses, the goal is for students to develop an engineering disposition through development of their attributes of being humanistic, creative, and technically excellent.

Characteristics of Pedagogical Features

The Studios described above are based on the notion of concurrent integration at a content- and meta-level as a learning strategy or experience that establishes the link between the courses in a curriculum, and promotes students' development into holistic engineers (see Figure 3). We propose that the Studios embody each of the following characteristics:

Project-based learning

Project-based learning is an extension of problem-based learning, but specifically involves challenges that are current, global, implementable locally, and ill-structured (Markham, Larmer, and Ravitz 2003). An important aspect of project-based learning is that it is student-driven. Concurrent integration involves learner-centered experiences that are motivated by the students' desire to learn rather than by the instructors' desire to cover material (National Research Council 2000). Additionally, this student-driven approach within a project-based learning environment will likely result in peer and near-peer learning and mentoring among the students (Smith et al. 2005; National Research Council 2000; Felder et al. 2000).

Service-orientation

Connecting material across the curriculum alone will not achieve concurrent integration. Concurrent integration requires the integration of concepts and knowledge with the local community, as this ties concepts and knowledge to the prior, current, and new experiences of students, resulting in deeper learning of concepts (Tsang and Zlotkowski 2000; Coyle, Jamieson, and Oakes 2005; Smith et al. 2005).

Deliberate reflection

Developing and encouraging reflection and metacognition will enable students to realize what they know and when they need to know more (Woods et al. 2000; National Research Council 2000; Kitchener 1983; Dewey 1933; Schoen 1987). Multiple opportunities for reflection and metacognition will encourage more learning to take place and potentially help students realize and achieve synergies between disparate aspects of their learning (meta-level integration).

Personal relevance

An important aspect of an integrated learning experience is that the issues and projects are personally relevant to the students. This provides a context in which to map fragmented concepts and understandings into a holistic understanding that will help provide intrinsic motivation. By focusing on relevant design challenges surrounding issues such as sustainability, concurrent integration will continue to respond to the changing global context of engineering (National Science Board 2007).

Synthesis-focused

Through explicitly connecting materials across the curriculum and across students' education, life, and prior experiences, they will begin to achieve content-level curriculum integration. At least one studio within the four-year Studio series will be trans-disciplinary in order to explicitly encourage this synthesis, while the other Studios will involve an interdisciplinary aspect in which, for example, creative ways of thinking and art-making are used.

Curricular Design Process for the Synthesis and Design Studio

In the implementation of the first Synthesis and Design Studio, the team of instructors discussed the overarching goals for the course, the desired emergent properties, and the outside influences, and developed a visual metaphor to reflect on and guide the curriculum design process (see Figure 4). At the center of the figure is a flower that represents a graduating engineer. At the bottom of the flower are the leaves and soil that helped allow the flower to grow and that represent the emergent properties of the Studio. The sun on the right side of the figure represents influences that are present but come from outside the classroom. The watering can on the left side of the figure represents the instructors' curricular choices. The watering can provides needed water so that the flower can grow from a seed. The water and the sun are both present and critical, but the watering can is all that the instructors can modify in the design of the course. This is similar to growing a plant in a person's yard. The person can change the amount of water that they give to the plant, but cannot control the amount of sunlight that reaches the plant after it has been planted.

The external conditions (design and influences in Figure 4) influence the emergent characteristics of students' learning experience (e.g., psychological safety as symbolized by the leaves in Figure 4) and are, in turn, meant to foster their development as technically excellent, humanistic, and innovative engineers (see the flower petals in Figure 4). More specifically, in the choices that we continuously make in the design of the Studio, we hope that the following properties of the studio experience emerge: psychological safety, ownership, personal relevance, higher-order cognition, and ways of thinking (see the leaves in Figure 4). We recognize that there are many influences that are beyond the control of the instructors. These influences include student motivation, curricular

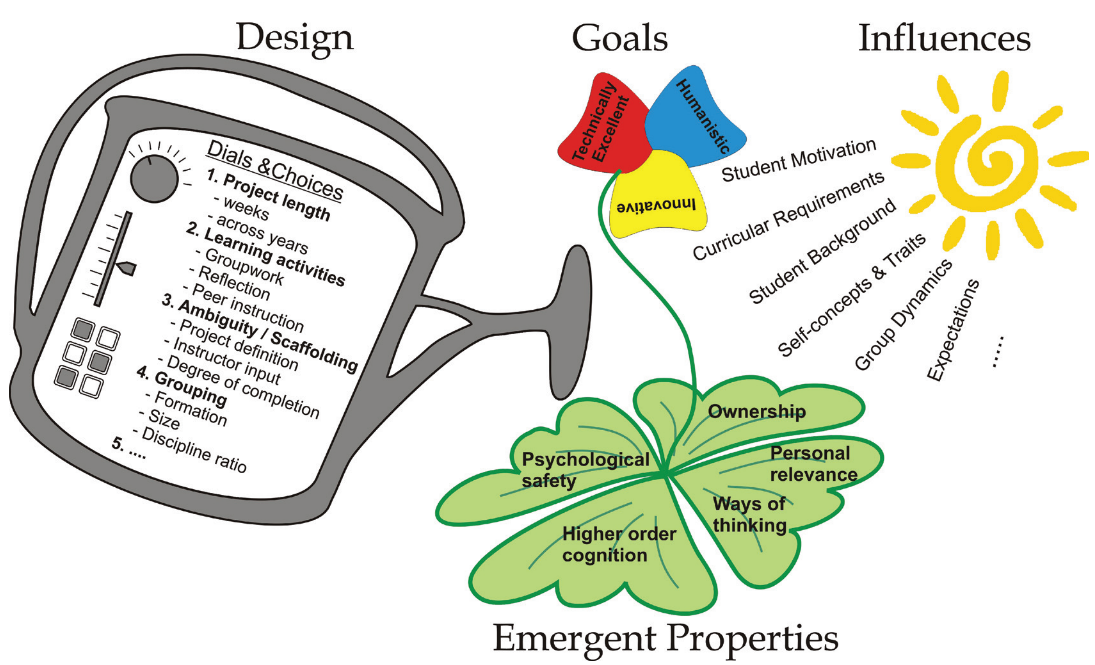

Figure 4: Visualization of the Curricular Design of the Studio showing our choices in the watering can, our overall goals, emergent properties, and influences

requirements, student background, self-concepts and traits, group dynamics, and expectations (see the sun in Figure 4). In our design of the Studio, we might modify and consciously deliberate the project length, the learning activities, the degree of ambiguity and scaffolding, the grouping, and the classroom environment (see the watering can in Figure 4). The project length might range from one class to a span of several years. The learning activities might include lectures, project work, peer instruction, book club discussions, reflection, and debates. The ambiguity of the assignments and projects might range from unambiguous to very ambiguous. The amount of scaffolding might range from no scaffolding to a high degree of scaffolding through course activities. The grouping of the teams might differ in terms of their makeup (number of students), size, and the length of time on each team, ranging from one small project to a project that spans multiple semesters. Finally, the classroom environment in which the Studio is taught might be modified. For example, an iteration of the trans-disciplinary studio might be taught in an engineering classroom, in an art classroom, or some combination of the two.

This visual metaphor allowed the instructors to consciously consider and make deliberate decisions concerning the aspects of the course that can be designed, while considering outside influences and keeping the desired properties of the learning environment in mind.

Organization of the Studios

At the time that this paper was initially submitted, four iterations of the Studio had been offered (Seminar Studio, Studio I, Studio II, and trans-disciplinary Studio III). The Seminar Studio and Studio II had been offered twice, whereas the others had only been offered once each (Studio I and III). The following illustrates the nature of the learning content and activities for the Studio series by describing one of the Studios (Studio II) in more detail.

The purpose of Studio II is to integrate the curriculum at both a content level and a meta-level. Studio II is offered every other year (even years), and includes environmental engineering students at both the freshman and sophomore level.

Curriculum Integration at a Content Level, Including Engineering Content

The specific content that is included to encourage content-level curricular integration is energy, sustainability, chemistry, technical communication, and project management. In particular, this studio integrates content from other freshman-level courses including LAND 2510, History of the Built Environment; ENGL 1101 and 1102; and English Composition I and II; and from sophomore-level courses including ENVE 2610: Introduction to Environmental Engineering and Sustainability; and CHEM 2211, Organic Chemistry. In addition, this studio introduces engineering concepts that will be included in later junior- and senior-level courses through a spiral curricular approach; these concepts include, for example: energy, urban systems, rural systems, economics, project management, and spatial data. The corresponding courses that students will take in their junior and senior year include, for example: ENVE 3210 and 3220, Energy Analysis I and II; ENVE 2320, Environmental Engineering—Urban Systems; ENVE 3520, Engineering Economics and Management; ENVE 4710, GIS for Urban Engineering, Planning & Development.

Curriculum Integration at a Meta-Level

Studio II also integrates the curriculum at a meta-level. This involves integrating ways of thinking, professional identity development, and connected ways of knowing. By focusing on ways of thinking, we explicitly emphasize students' development in their creativity and complex systems thinking through, for example, the introduction to and use of visual thinking tools (Senge et al. 2000). In focusing on their professional identity development, we focus on projects in which students act in the role of the engineer, and subsequent reflective activities in which the student reflects on their professional development as an engineer. Finally, we focus on connected ways of knowing in which students develop an understanding of how systems are interconnected, how their learning is interconnected, and how their personal experiences are connected within their ways of knowing. The following description of the course project, deliverables, course reader, and course reflections further illustrates the practical implementation of these features.

Project 1: How can we embed less energy in our food?

This is an individual project that involves the development of an awareness campaign to address the amount of energy embedded within food. Students are required to conduct observations of an aspect of the local food system, complete a personal food log, and conduct research on the energy embedded in food. The deliverables include a poster and a report that incorporates all aspects of their project.

Project 2: Athens new 60-mile diet proposal

This is a group project that involves the design and writing of a magazine article describing a hypothetical proposal to restrict all food in Athens, Georgia to a 60-mile radius, and the production of an opinion video that represents the opinions of the team members concerning the 60-mile diet proposal. The magazine article must include facts, figures, and voices from local stakeholders, while the opinion video can be fictional and include the possible consequences of the proposal.

Project 3: Casting call video

In continuation of Project 2, this project involves the development of a claymation video centered around the concept of sustainability. The video also includes one visual metaphor of sustainability that each student creates and combines with a voice-over to represent their personal understanding of sustainability (see photo elicitation in Jordan et al. 2009).

Project 4: Sustainability proposal

The final project involves each team developing a sustainability proposal that will be presented to the Mayor of Athens, who in the scenario proposed the initial restriction on food transportation. This project is more ill-structured than the other projects, while building on background knowledge gained in the three prior projects.

Theoretical framework (course reader)

In addition to the projects, this Studio involves readings as well as subsequent discussions and reflections on these readings. The course readings are structured around the role of engineers within larger socio-technical systems. Included are readings that highlight the unintended consequences of engineering work, discuss the systems perspective and the social context of engineering practice, explore the relationships that engineering work is embedded within, and discuss the necessity of a moral stance for engineers.

Reflections

To encourage holistic student development, reflections are included throughout the studio. These reflections include short written reflections, visual journal entries, focus group discussions, and a reflection report at the end of the semester. These reflections help students realize their personal and professional development over the course of the semester.

Studio II was described in this section to illustrate the intention and design of all of the Studios in the series. The Studio Seminar I similarly includes a theoretical framework (course reader), discussions, and reflections. Studio I is similarly structured with all of the components as described in Studio II above; however, the projects take place within a local industry and the students frame and develop a sustainability proposal for that local industry. Studio III is a trans-disciplinary studio that is comprised of environmental engineering students, art students, and instructors. Studio III focuses on water resources in urban systems, and allows for more content integration, as the junior students have taken more advanced level courses. Studio III also involves trans-disciplinary teams and has a strong focus on the meta-level integration of the curriculum through a focus on creative and connected ways of thinking.

Creating Space in the Curriculum for the Studios

Based on the above descriptions, the question arises as to which classes traditionally included in engineering curricula were left out to make room for these new Studios. In each year of the curriculum, different strategies were employed to create space for these Studios.

The curriculum typically offered a three-hour, freshman-level course that focused on learning how to draft using AutoCAD, and included seminars by professional engineers. Because the Studio is a design course, there are many instances throughout the sequence when there is a need for students to learn technical drawing. The Studio includes a series of workshops within these projects, first on hand sketching and then on drafting with AutoCAD, and specifically involves projects that require the students to create technical drawings to specifically develop this engineering skill. In addition, during the Studio Seminar, outside speakers are brought in to hold seminars to help the students make connections between their education and their future professional lives. Thus, the freshman Studio sequence (Seminar Studio and Studio I) replaces these three credit hours that were traditionally included in the curriculum for AutoCAD and seminars. Typically, the engineering curricula offered at our university include a design course offered at the sophomore level. The Studio is a design course focused on design projects and project management throughout, and thus the hours from the sophomore-level design course are allotted for the Studio. Finally, during the third year of the curriculum, students typically participate in upper-level technical courses and electives. The third year Studio is centered on the concept of water, and thus takes the place of one of the upper-level electives.

These are three examples of how we fit the Studios into an already overcrowded curriculum by including the content covered in other classes as part of the projects in the Studio Sequence.

Engineering educators at other universities wishing to implement Studios in their curricula will also need to think about the focus of their Studios in particular, and how they can replace some of the existing courses in the curriculum with a Studio that will still cover the engineering content and material that was included in the original course. Courses that are easily aligned to the Studios and can be substituted for Studios are design courses, courses that focus on learning to use a software package, and electives whose content will be researched and explored through the proposed design projects.

Challenges Encountered when Implementing the Studios

Since the first Studio was implemented in Fall 2009, there have been some unforeseen challenges. These include scheduling, credit hours earned, and class size for the trans-disciplinary Studio III, and will be described below.

The first Studio implemented was the trans-disciplinary Studio. The greatest challenges with implementing this Studio were administrative in nature. At first we attempted to cross-list the course, but discovered that if we cross-listed it only one instructor would get credit for teaching the course. Instead, we listed two separate courses in two separate departments (Art and Environmental Engineering) that met at the same time. On the first day of class, we met in the separate buildings and drove the engineering students over to the art school. After that first class, we held the Studio in the art school on Mondays and in the engineering school on Wednesdays. This solution allowed the instructors to get credit for their respective sections of the course and for the class to be offered in two physical locations.

Another challenge that has not yet been resolved is that not enough credit hours have been allotted to the Studios. Currently students spend six contact hours per week in the classroom as well as extra time outside of class but earn only two credit hours. Many have explained that they spend more time and effort in this class than in any of their other classes. Fortunately, the students seem willing to spend more time and effort in this class because of its active and project-based nature. The plan is to eventually combine two of the engineering science classes into one four-hour class so that two more hours can be allotted to the Studios.

The class size has also been challenging. In the first implementation, we limited the size to 25 students. This size seemed to work well for the structure and hands-on nature of the class. In the second iteration of the Studio in the Spring of 2010, we had 45 students enrolled with two instructors. This size was difficult, especially during class discussions around readings or weekly team updates. In the third iteration of the Studio, we limited class size to 25 students per section with one instructor each, and this size worked much better. For the first Studio Seminar, we had 55 students, but also found that it was too large for class discussions and activities and have now limited the Seminar to 25 students per section.

There have been some other challenges in this initial implementation of the Studios. Scheduling has been a challenge because the Studios are held for six hours per week. Also, there has been some challenge in planning the freshman Studios because there is no limit to the number of students that can enter the program. To overcome this, we now offer a Seminar during the first semester of the freshman year so that we can plan for the subsequent semesters accordingly.

QUALITATIVE INVESTIGATION OF INTEGRATION IN THE STUDIOS

The purpose of the problem-led research described in this paper is to represent and analyze the students' shared lived experiences while engaging in the Synthesis and Design Studios (Seminar, Studio I, Studio II, and Studio III). This study will emphasize impacts on student learning, and particularly how the students experienced the curriculum innovation of the Studio that was conceptually described above. We will analyze the data collected from each of the four implementations of the Studio that occurred from August of 2009 until May of 2011 through focus groups and process reflections.

During the time that the Synthesis and Design Studio has been in place, the researchers have collected a comprehensive data set including pre- and post-draw an engineer (and artist during Studio III) pre- and post-design process drawings, pre- and post-Torrance Tests for Creative Thinking, field notes, artifacts including project deliverables, written reflections in visual journals, written process reflection reports, and audio-recorded focus group reflections. An analysis of the entire data set is beyond the scope of this paper. However, the transcripts of the reflective focus groups and the written process reflections were found to be particularly relevant to students' experiences of integrative learning, and thus form the focus of the analysis presented here.

Participants

The participants of this study were students enrolled in the Studios that were offered between August of 2009 and May of 2011 (Seminar Studio, Studio I, Studio II, and Studio III). The total number of participants was 139, with 85 males and 54 females (see Table 1 below for the breakdown of students per Studio). Data were collected from these participants during focus groups and from written process reflections. Each student participated in one to three focus groups, depending on the class. The focus groups were based on critical incident techniques (Walther and Radcliffe 2007; Walther et al. 2009; Flanagan 1954; McClelland 1973; McClelland 1998), included 5-8 students per group, and were facilitated by the course instructors and graduate students who were trained to facilitate these focus groups by the researchers. The focus groups were audio-recorded, transcribed, and entered into NVivo 8 for an interpretive data analysis. Students were also required to submit a written process reflection at the end of the course. In this reflection, students were prompted to reflect on and synthesize critical learning incidents that they identified during focus groups and from the reflections in their visual journals. They were instructed to follow the SAID framework that was followed in the reflections after each focus group. The SAID framework involves identifying the Situation, Affect, Interpretation and Decision Making when recalling and making sense of a critical learning incident (Walther and Radcliffe 2007; Walther et al. 2009; Hogan 1995). These reflections are thus a culmination of multiple reflective activities in the course, including participation in focus groups and journaling.

Qualitative Data Findings

To illustrate the usefulness of both the overarching model and the pedagogical features beyond the detailed description of their implementation, the following explores students' accounts of integration as they participated in one of the four Studios offered to date. This is not intended to serve as a comprehensive evaluation of the pedagogical innovation, but rather to fill the description of theory and instructor intent with the life of students' shared experiences of the course. These findings will be presented by beginning with concrete course activities and components, and transitioning to the more abstract, personal and professional development processes that students attributed to the Studio experience.

Many students discussed the course projects in a way that indicates the development of an integrated understanding of Environmental Engineering. In Studio II, a student described how the realistic and local nature of the project helped him be more motivated and interested in the project. This project involved developing a sustainability initiative at the local brewery, Terrapin.

		Number of Participants		
Class	**Semester Offered**	**Male**	**Female**	**Total**
Seminar Studio	Fall 2010	31	17	48
Studio I	Spring 2010	25	12	37
Studio II	Spring 2011	22	13	35
Studio III	Fall 2009	7 (6 ENVE, 1 Art)	12 (3 ENVE, 9 Art)	19

Table 1: Participant details for the four Studios completed to date

> *What I like about this whole Terrapin project was, as environmental engineers this could actually be something we might do in the future. As opposed to just crunching numbers, equations and stuff all of the time.*

This illustrative quote describes how personally relevant and local projects helped provide additional motivation and interest in the project. It also demonstrates a difference between the primary activity in other engineering classes ("just crunching numbers") and this more realistic project, which represents a larger socio-technical system that students might encounter as future Environmental Engineers.

Another commonly mentioned aspect of the projects described in the focus groups and written process reflections was their open-ended and ill-structured nature. Many students discussed their initial frustration with the open-ended nature of the projects, and then later their excitement at having flexibility to frame multiple problems within the larger system and eventually propose many different solutions to these problems. Many students mention that these types of problems are initially frustrating because they have never encountered ill-structured problems in their education before. A female student from Studio I explained:

> *And I was like, it's [the project brief] not specific enough. You know, the food and energy. That's so broad. You could do so many different things with it. So it was—at first, I was like, What do they want us to do with it? But then after that, when I realized it was different from the other classes, I just realized that you can do whatever you want!*

This student's quote describes her transition from frustration when given the open-ended project brief to excitement about the multiple, possible directions that she could take with the project. This student's description of her coping with ambiguity suggests that she is becoming more comfortable in dealing with complex, ill-structured problems, thus developing a deeper understanding of the need for and possibilities associated with utilizing and integrating knowledge across several domains.

Within the discussions concerning the open-ended structure of the projects, many students mentioned that the near-peer component of the course helped them cope with the uncertainties surrounding the projects. Studios I and II include both freshmen and sophomores in each section of the class and within each team to encourage near-peer instruction. One female student described this near-peer learning as she experienced it:

> *But it was relieving to have one of the old cohort members kind of step in and take the leadership role and kind of direct us in what was expected of us in the project and what*

their experiences had been, because it had kind of provided more of a construct to what the project was supposed to be, so it went from being this open-ended project to an open-ended project with kind of a little bit of boundaries and an example, more or less, to work with.

In the discussions of the perceived benefits of near-peer learning, students also described that having the older cohort present encouraged them to take more risks and prepare more creative project deliverables. One male student described this as "having that security blanket of knowing what you're supposed to do allows you to get over the confusion and get over the uncertainty of [the project]…so you don't pick necessarily the safest option, you pick an option that is what you would see as most efficient." This near-peer component of the Studio appears to be important for the students to feel comfortable working within the open-ended projects and, more importantly, they describe this component as being critical to allow them to take more risks and propose more creative problems and solutions.

A way that content-level integration occurred in the trans-disciplinary Studio III was in the focus of the projects being on energy within different sectors for different teams, including residential, commercial, ecosystem, infrastructure, transportation, and food. The following excerpt from a focus group describes how one student realized the breadth of connections between these sectors when they participated in a class activity in which each group drew a concept map and then made connections between the concept maps with yarn.

Male 1: I think the best one [example of a class activity that helped them better understand the project] for me was concept mapping. When we linked them all together with the yarn, to really see how similar they really are.

Instructor: So when you say that, for your example, the concept mapping. What was it that you…

Male 1: Making the connections between the groups.

Instructor: Ahh, between the groups.

Male 1: Yeah, because I didn't really think about [the connections], you know. I mean, the only one I connected with was thinking about transportation, but really they're all connected in some way.

This focus group excerpt describes how students began to realize the interconnections of the multiple systems within our society.

Within the Studios there is a focus on framing problems within a larger, socio-technical context. Many students discuss this change in focus as a departure from their prior and current schooling, which focused on solving problems. In the trans-disciplinary Studio III, a female art student discussed her initial uneasiness about framing problems and subsequently her resolving this concern, “If you even watch a documentary about something, like a problem in the world, they don’t really spend most of the majority of the time talking about the solution. They talk, the majority of the time, about all the problems. So, I don’t know. That format seems to work well.” Many students discussed their difficulties in working within the complexity of an issue to frame a specific problem. Most had a tendency to move quickly to solutions before even framing a specific problem. One student described this as going “too deep too fast,” and throughout the semester they continued to experience a tension between proposing solutions and framing problems.

Throughout the focus groups and personal process reflections, many students mentioned other aspects of the class that helped integrate learning across their different courses and different aspects of their lives. These included the claymation activity, body sculptures, the toxic waste activity, the debates, and the readings (especially the case studies). A female student enrolled in the Seminar Studio mentioned this wide range of activities and how they helped prepare her for her future career as an Environmental Engineer:

> *Over the course of the semester, our professors helped to prepare us for the challenges we’ll face in our careers by presenting us with atypical engineering-class assignments. Some of these assignments required us to work in groups, such as our exploration of the problems with paper usage in the engineering building. We found that the issues weren’t always as simple as they seemed at first glance, for example, when we conducted a debate, in which we practiced our communication skills while opening our eyes to the wide array of opinions and perspectives that abound about each topic. Through each essay, poster, and concept map that we created, we drew connections and developed thorough understandings about topics that any amount of calculus and physics could never have taught us.*

This quote demonstrates how this student experienced the Studio Seminar, and she explicitly discusses how the class activities led to a deeper understanding of how different topics were connected, in other words, how her learning was integrated through this class.

Many students described personal or professional development through their Studio experience. In Studio I, a male student described a requirement within the first project to observe the local food system. In a focus group, he described how he transitioned from thinking this requirement was useless to having it change the way that he perceived the world to the point where it has led him to consider a different professional career in architecture once he finishes engineering school. The following is his description of this transformation:

Male: People ask me "When you graduate, what do you want to do with that [degree]?" And I'm, like, "I don't really know. What *can* you do with it?" I guess for me it's kind of of these observations. I really started to realize a lot of things I enjoy, things I would like to do, things I would like to change, and I'm starting to look into more of an architectural side and being more—maybe going to grad school for architects.

Facilitator: Great.

Male: And then taking a background of environmental and being more of a—you know, making sure when I build something as an architect, though, to have more of a sustainable outlook on—so, that's been something I realized. It was just that mindset of changing to actually stop and observe things.

The notion of observing systems was an overarching theme of Studio I. This student quote describes how the experience of going into the community to collect field notes through observation changed the way that he perceived the world around him and his future professional plans. This is an interesting example of the notebook metaphor described earlier in this paper, where the Studio provides an integration of curriculum, life, and prior experiences.

The Studios also focus on interviewing stakeholders in the community. A female and male engineering student discussed their personal realization that interacting with and interviewing stakeholders in the local community can help develop an understanding of the socio-technical system in which their specific issue was embedded and of other people's perspectives. They also learned that people were eager to share their perspectives and backgrounds. A female student explained,

…My job was to contact the farmers. And I was, like, Oh, this is kind of awkward. I don't know these people, and they're gonna be like, "Why are you asking me questions?" But it was, like, a lot of them had a lot to say, and so that was really interesting to hear from them, because I had never really asked the farmers' opinion on anything, so it was, like, Wow, that's a new experience.

And a male student responded, "Yeah. I figured out that if you ask people who are knowledgeable about something, they'll happily just tell you what they know." This is an example of how students began to integrate their education with the local community and build confidence through interviewing stakeholders.

Students also experienced this personal transformation in the trans-disciplinary Studio III. Many students reflected on a personal transformation where they first experienced different ways of thinking, and then later experienced an integration of multiple ways of thinking within this trans-disciplinary context. A female art student explains this process of personal transformation:

> *The process itself comes in waves; I wrote on the first day of class in my journal that while "working with others that have different strengths, we can aim to think in different ways ourselves and benefit from the experience." I really do think that this is exactly what I have done. No, this did not happen all at once, rather it was a growing process in which I struggled, argued, disagreed, and was in turn argued with and disagreed with as well.*

This quotation describes how the students experienced a meta-level integration of ways of thinking within the class. This student describes the process of integration being one of recognizing differences and then beginning to "think in different ways ourselves." She also describes that this was a gradual, not sudden transformation in her personal development.

The trans-disciplinary course with engineering and art students appeared to make this meta-level integration very explicit to many students. A female art student explained this process in the following:

> *At first, it was a struggle for all of us to realize that we were all capable in each other's subjects or approaches—a logical, linear way of work that is associated with engineering, or a more intuitive, creative way of work that is associated with art. There was tension as some members refused to let themselves see that they were imposing these boundaries upon themselves. But overall, we overcame these stereotypes and were able to better collaborate with each other, and instead of approaching the same subject from different directions, branch out and strengthen the approach that we started as one unit.*

This student explains the process of engaging in a trans-disciplinary course as he began to see the unified ways of thinking that are common to both artists and engineers.

Studio students also described a change in their attitudes or preconceptions about other ways of thinking. They developed a genuine appreciation of the societal relevance of such new ways of thinking. Elaborating on this meta-level integrative experience and on the resulting change in his preconceptions of artists and engineers, an engineering student commented:

> *This course helped me eliminate my stereotypes of artist and engineers, so I can see the broad scope of possible applications of art and engineering in society; particularly, the fusion of the two disciplines can be synergistically productive.*

In addition, a male engineering student described how his attitude towards artists and artistic ways of thinking was challenged when he realized the artists' strengths that he saw as needed for his future career as an engineer:

> *Throughout the semester I kept on asking myself: "Why? Why? Why?" How has their training enabled them to be so good at things that engineers are supposed to be able to do better than anyone else? The most important being: brainstorming, creative thinking, and the heightened ability to understand the physical world around us.*

Throughout the Studios, there is a recurrent theme of complex systems and systems thinking. This is supported by readings specifically discussing complex systems and systems thinking, and case studies of environmental engineers and their projects. One student discussed how her perspective of Environmental Engineering changed through this focus in the class on the systems view. She discussed a change from an anthropocentric understanding of Environmental Engineering to a more ecological, holistic understanding of the role of Environmental Engineering:

> *Unlike my preconceptions, where I thought an environmental engineer would work alone in an office designing new innovative ideas, the modern environmental engineer looks at the world more as a system. By looking at the world in the systems view we can no longer rationalize saying that human beings are independent and masters of their environment. The systems view that modern engineers use recognizes connections and communications between humans as well as between humans and their environment. This was a shift [from] viewing situations as individual problems to viewing a particular situation as a part of a whole system, where actions must be carefully thought out because of their implications on the situation but also on the system as a whole.*

Her reflection indicates that she is beginning to understand the importance of indirect effects and emergence, both critical concepts within systems thinking.

The observation of such developments within student reflections and focus groups, with a view to helping students develop an integrated understanding of Environmental Engineering, is promising. These findings indicate that the Studio series, as described theoretically and in more detail in this paper, does result in students' perceptions of an integrating experience. Future work will further evaluate this, and explore the interplay of specific influences and the range of concrete outcomes, in order to share an effective model for integration in engineering education curriculum well suited to the challenges of the 21st century.

DISCUSSION

The findings that were reported in this paper are closely tied to the theoretical discussion of this curriculum integration project. For example, in section 3.5 we discussed characteristics of the pedagogical features of the Studio. Each of these features was discussed in the context of the research findings reported in the section above. Many students discussed the project-based nature of the class and the focus on open-ended projects, and how these influenced their understanding of engineering as being situated in a larger, socio-technical system. This more holistic understanding of engineering practice appears to serve as a catalyst for developing an understanding of the content-level integration of seemingly disconnected knowledge and disciplines. Also, students discussed the service orientation of the projects. For example, they discussed observing and interviewing stakeholders as significant learning experiences in the Studio. The students described these experiences as helping them build confidence in their value in the local community and explore their development into future engineers (or architects, as discussed in the example above). Through their involvement in the local community through their projects, the students began to see how engineering problems are integrated within the local community. A final example of the links between the pedagogical features of the Studio and the findings from the student focus groups and personal reflections can be found in the synthesis-focused nature of the class. Many students discussed going “too deep too fast” in their projects, but then later described how they appreciated and understood the dangers of solving a problem when the problem has yet to be framed. This pedagogical feature was supported by the projects, readings, and class activities, and resulted in students’ understanding the importance of systems thinking, so that they can develop a deeper understanding of the systems within which their problems and issues are situated.

The findings discussed in the section above are primarily focused on meta-level integration of the curriculum. This may be due to the nature of the data collected through focus groups and personal reflections. These reflections are often focused on the processes of learning and not on the specific content learned. Future research that is focused on content-level integration would be helpful, as this may be an area that can be improved in future iterations of the Studio.

This paper might serve as a catalyst to expand our understanding of current engineering education initiatives, in that it demonstrates multiple ways to integrate the engineering curriculum at a meta-level, which promises to be important in developing the critical thinking as well as innovative and creative capacities of our students. The Synthesis and Design Studio sequence demonstrates some variability in the ways that a curriculum integration project can be implemented. The Studios range from a one-contact hour weekly seminar to a six-contact hour Studio. Also, they range from including freshman and sophomore-level Environmental Engineering students in the same class to trans-disciplinary classes with equal numbers of art and engineering students. The first Studio offered was trans-disciplinary, and there was concern that engineering-only Studios would not be as effective at integrating the curriculum. However, the subsequent Studios demonstrated that it is possible to integrate the curriculum effectively even when there is not such a perceived difference between the ways of thinking of the course participants.

There appear to be many benefits of the trans-disciplinary Studio in integrating the curriculum at a meta-level. This may be due to the larger gap in the ways of thinking in apparently diverse disciplines such as engineering and art. This promotes more opportunity for the personal development of students as they first realize that they think differently than the other students, and then a greater chance for an epiphany when they realize that they can effectively engage in multiple ways of thinking, and often think similarly (e.g., with an emphasis on design) (Root-Bernstein and Root-Bernstein 1999). However, Environmental Engineering Studios I and II have resulted in meta-level integration of the curriculum as well. Part of this integration could be from focusing on arts-based learning that challenges students to engage in artistic ways of thinking. Arts-based learning projects such as producing videos and magazines, creating stop-motion animations, and developing awareness campaigns might help emulate this diversity of ways of thinking found in the art and engineering Studio. Future research is needed to determine the success of integrating art into engineering courses, as this is likely more easily accomplished in an existing engineering program that does not have the ability to completely revamp the curriculum and include something equivalent to the Synthesis and Design Studio track. Arts-based learning projects might be included in a project-based learning course or a lecture-based class through a standalone project that complements the class's learning objectives.

CONCLUSION

The innovations described in this paper were implemented in a new Environmental Engineering curriculum. It is important to note, that although this was a new curriculum, most of the members of the curriculum committee were from the existing Biological and Agricultural Engineering department and had very specific ideas about how the curriculum should be structured. To date, this curriculum innovation has been successful, and it will be interesting to see whether other existing and new undergraduate engineering degree programs in the College of Engineering adopt a similar approach. The authors understand that most engineering programs are not in a position to make large-scale multiple-year curricular changes in order to emulate this kind of curriculum innovation project. It is possible, however, to adopt a few of the pedagogical features discussed in this paper to modify a specific class or set of classes within an existing curriculum. Which of these features to adopt is dependent on the specific context of the current curriculum being considered.

This paper also conceptualized curriculum integration as being important at two levels: a content-level and a meta-level. Content-level curriculum integration involves the integration of content (engineering or non-engineering) and concepts. This type of curriculum integration is commonly found in engineering curricula through capstone design projects and freshman design experiences. More recently examples of engineering faculty achieving this content-level integration have occurred through a spiral curricular approach (see Lohani et al. 2011 as an example). The proposed curriculum integration innovation, the Studio concept, addresses both content-level integration and also a meta-level curriculum integration. This meta-level curriculum integration involves an integration of students' ways of knowing and understanding, and is achieved through both a focus on creative and interdisciplinary ways of thinking and the inclusion of a strong reflective component in the Studios.

This paper not only demonstrates the curriculum innovation of the Studios, but also the thinking that went into the design and development of the Studio and how it came to be what it is today. The figures that describe the process we engaged in when designing this integrated series of courses can be applied to the design of other curricula and individual courses. One can easily and readily adopt some of the pedagogical features found in the Studio into engineering and non-engineering courses alike. These pedagogical features involve project-based learning with ambiguous projects, deliberate reflective activities, and interdisciplinary experiences.

In this paper we described the development of an integrative engineering learning experience and illustrated the process using transferable visual metaphors. The resulting curriculum innovation was described in detail, with examples of learning content and activities. Qualitative, problem-led research was included to provide an indication of the integration of the curriculum through the students' reflections concerning their perceptions of the integration of different disciplines and ways of thinking. This integration of the engineering curriculum through the Synthesis and Design Studios promises not only to deepen students' depth of knowledge within their own discipline, but also to draw connections between engineering and other disciplines, many of which are required to begin to tackle today's complex problems.

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