Developing and Teaching a Multidisciplinary Course in Systems Thinking for Sustainability: Lessons Learned through Two Iterations

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Abstract

Industry is calling for more than technical skills from those graduating from engineering programs. At the same time, looming grand challenges such as climate change and sustainability require multidisciplinary research and development approaches by teams that include more than the so-called hard sciences. Systems Thinking for Sustainability (SFTS) is an innovative team taught cross-disciplinary course for undergraduates from four colleges—Engineering, Design & Architecture, Education and Business/Economics—developed to address the current disciplinary isolation of students and educators in STEM fields in order to improve undergraduate STEM education. The initial hypothesis was that the challenges of communicating about the difficult-to-define collection of problems called sustainability across different disciplinary boundaries during project-based work would provide the student teams and the faculty team with valuable experience and increased skill in working in such cross-disciplinary teams, which have been common in the workplace and are growing more common in the university and in government[1]. It was also hoped that this STFS project might be pioneering at University of Kentucky and elsewhere, encouraging those students and faculty in the "hard" fields such as engineering to venture out across boundaries into further collaboration with those in the so-called "soft" fields. Here, addressing sustainability issues was chosen because they involve complex connected systems which demand cross-disciplinary approaches.

This paper elaborates, primarily from the point of view of the engineering faculty participating, the significant challenges faced and lessons learned in designing and delivering STFS during the first two years. It summarizes the results of extensive discussions that were required to identify and agree upon course content, the different pedagogical methods used, team teaching efforts, and faculty roles and responsibilities. Methods of evaluating student learning as well as identifying and managing the course team projects are also discussed. The paper concludes with some brief lessons learned to help others who might be interested in pursuing a similar project.

1. Introduction

The importance of developing a skilled and knowledgeable STEM (science, technology, engineering and mathematics) workforce is now well-recognized[2]. By 2020 the US will require 123 million highly skilled workers to fill positions in the STEM fields for which there will only be 50 million qualified candidates[3]. The US is consistently ranked lower than anyone would like in the quality of math and science education compared to other nations (47th in 2012-2013) [4]. Transforming undergraduate education in the STEM fields, therefore, has received increasing attention over the last twenty years[5, 6, 7, 8].

In this context, one recent study by the American Society of Engineering Education (ASEE) draws attention to the need for and the nature of transformation required in undergraduate *engineering* education[9]. The report emphasizes that while industry continues to seek engineers with solid foundations in math and science, these foundations must be complemented by skills in programming, systems thinking and the ability to use relevant tools. Further, these new engineers must possess a variety of 'soft' skills (i.e. interpersonal and communications skills) as well as a grasp of economics and business acumen.

The need for changes in the approaches used to teach future engineers and instill the necessary Knowledge, Skills and Abilities (KSA) is also emphasized. These KSAs are reflected in the desired outcomes of STEM education outlined in recent versions of professional accreditation criteria. For example, seven of the eleven current ABET (Accreditation Board for Engineering and Technology) criteria for accrediting university engineering programs[10] either state or clearly imply a need for engineers to be competent in systems thinking and teamwork/communication, to understand the issues of sustainability, and to work effectively on cross-disciplinary problems. A selected set of (mostly non-technical) KSAs identified as important by a survey conducted at the ASEE-NSF workshop[9] and which stakeholder(s) must be responsible to teach them (in percentages) are shown in Table 1. The numbers within parentheses next to each KSA indicate its priority in the list of 36 KSAs identified through the survey. The sample data presented below shows the critical role engineering educators have in instilling these KSAs in the future engineering workforce.

While some of the KSAs identified can be integrated into existing courses through creative curricular revisions, many others require more customized transformative efforts: for example, systems thinking skills, the ability to work in multidisciplinary teams as well as building an appreciation for global, social, intellectual and technological responsibility are difficult to instill without designing a course for students from multiple disciplines engaging in problem solving practices collectively. Only such experiences can expose students to the challenges of working across disciplinary boundaries so they learn to appreciate the different skills and assumptions of other stakeholders in order to find effective and workable solutions to complex real-world problems. At the same time, working with different skills and assumptions gives them a clearer sense of their own.

That is, students and faculty in such a course would be working in areas typically kept separate in a standard undergraduate education, the kind where those who study scientific and technical realities work in isolation from those who study cultural and political realities and vice versa.

Table 1: Selected KSAs and Responsible Stakeholders[9]

KSA	Responsibility						
	Academia	Industry	Government	Students	Parents	Combination of two or more*	Other
Good communication skills (1)	23%					73%	4%
Systems integration (4)	13%	13%				71%	4%
High ethical standards, integrity, and global, social, intellectual, and technological responsibility (9)	12%		4%	4%	12%	68%	
Critical thinking (10)	71%			4%	4%	21%	
Ability to prioritize efficiently (12)	17%	8%		8%	17%	50%	
Teamwork skills and ability to function on multidisciplinary teams (14)	33%	4%		13%		50%	
Creativity (23)	33%			6%		61%	
Systems Thinking (24)	22%	17%				56%	6%

*indicates responsibility is shared by two or more of the parties listed to the left

This separation is not helpful when approaching sustainability issues. For example, as Vaclav Smil reminds us, "Energy decisions involve often irreconcilable considerations of thermodynamic efficiency, personal comfort, resource depletion, economic well-being, environmental degradation, national security, social stability and democratic values"[11].

This area where energy decisions are made is "messy" by definition, not well served by operating from within academic disciplinary borders. Therefore, questions of sustainability can provide students and faculty a rich assortment of "wicked" problems[12], those whose interwoven social and political factors preclude solutions that can be made entirely on technical grounds. In this way, a focus on sustainability makes multidisciplinary teams a pragmatic necessity rather than classroom artificiality. Or so it was hoped.

Other institutions may be more radical in these matters but at University of Kentucky, engineering faculty were cautious and rather leery about collaboration outside the discipline. In fact, it was in the not so distant past considered a bold and risky multidisciplinary activity when an electrical engineer collaborated with a mechanical engineer. However, given the interest from industry for broader skills and faculty interest in tackling sustainability and in improving STEM education, it was clear that, ready or not, engineering faculty needed to work with those in other disciplines who did not share the same assumptions, nor value the same tools for analysis nor prize rigor above all.

The vehicle chosen was a project to design and then deliver a team taught cross-disciplinary course for undergraduates from four University of Kentucky colleges: Engineering, Design & Architecture, Education and Business/Economics. The project, funded by a National Science Foundation grant, uses the lens of systems thinking to approach sustainability. Students are first introduced to the relevant systems and sustainability concepts, issues and challenges. Student teams are then asked to select a problem, investigate, exchange and integrate new tools and techniques from the disciplines that were supplied during the presentations to solve the problem or improve a suboptimal situation, using sustainability as one of the criteria for success and identifying the system or systems relevant to their project.

Such an ambitious course is likely to encounter difficulties, aside from the general human resistance to change all new ideas face. Typical problems encountered in delivering innovative courses have been extensively discussed in the engineering education literature. Most relevant to the STFS project were the following: (1) Students may resist changes in instructional approaches because they have become accustomed to memorizing terms and facts and receiving information from the instructor in a one-way fashion and have developed strategies to succeed in such courses. In addition, students trained in quantitative fields can tend to dismiss other approaches as at best alien and at worst invalid or worthless[12, 13]; (2) Students will have preconceptions (often erroneous) about concepts in their or other fields, which they may hold on to stubbornly and are unlikely to change unless specifically addressed by instructional strategies[8].

These and other challenges, in particular related to individual faculty disciplines and/or system administrative rigidity, will be discussed in more detail in the sections below.

The remainder of this paper is organized as follows. Section 2 provides an overview of the general structure of the course and contents delivered. Since the project's inception in July 2011, two iterations of the STFS course have been taught with the third ongoing during Spring 2014. Experiences from developing and teaching this course, in terms of faculty-, student-, and administrative/logistical-related issues, respectively, during the two iterations and the changes done to overcome those difficulties are discussed in Sections 3-5 with special emphasis on engineering. The improvements planned for the third iteration in Spring 2014 and further insights gained through the experience are shared in the final section of the paper.

2. STFS Course Structure and Contents

Using systems thinking to approach sustainability was chosen for several reasons: (1) because a systems thinking approach was a practical rationale for multidisciplinary team sustainability projects[14], (2) because systems thinking is an appropriate education approach to complex problems[15] and (3) because a basic broadly applicable form of systems thinking (System Dynamics[16]) could be quickly provided it was assumed as a kind of common language for students from different disciplines. As such, the STFS was designed to promote cross-disciplinary collaboration and improve communication and team working skills[17]. To effectively implement team work, a two part structure was chosen for the course: the first phase of the semester introduces students to the various concepts relevant to sustainability and systems thinking as well as tools to analyze and solve problems in these domains; the second phase of the semester was devoted to extensive team project work [see[17, 18] for some more details of syllabus outline].

Differences between disciplines in the approaches to basic concept selection and problem definition, assumptions used as well as developing solutions meant that there was a need for some basic agreements, such as adoption of an agreed-on definition of *system* and *sustainability* in order to make the cross-disciplinary collaboration effective[17]. This was one of the primary goals in the first phase of the course. Another important assumption from the point of view of engineering was that the selection of a problem (a large unifying “umbrella" problem that would provide many smaller projects) should not be limited to those typical of engineering systems. On the contrary, it was felt that the engineering students would benefit from and would be an asset to the team when working on a more broadly perceived wicked problem of sustainability. This phase of the semester was designed for instructor led presentations and discussions, with all instructors attending almost all the sessions. Concepts and tools were borrowed from the different disciplines with the primary (session) instructor leading the discussion and other instructors contributing input on how the material would relate to their own disciplines. Students were also provided with a variety of supplemental reading materials including journal/magazine articles, book chapters, video clips, etc., intended to enhance their understanding of new topics as they were introduced and to reduce the amount of instructor presentation. Following each session, student teams (members changed from one session to the next) are asked to respond to a topical issue or apply the tool and all the teams’ findings are presented in-class with immediate feedback from all instructors present. A sequence of assignments was developed during phase I including those that challenged students to define a system, communicate that system simply and clearly as a narrative, broadcast awareness of the system in the form of a public service announcement, and model and analyze the system behavior under different circumstances[17]; the in-class team activities were designed to guide students to better address these assignments.

The second phase of the course is devoted to project work. The "umbrella" project was chosen to give the course coherence and to motivate the student project teams with a goal beyond the individual class assignments. Therefore, “campus living” was chosen as the umbrella project. Multidisciplinary student teams were to choose a sustainability-related issue that could be addressed as a project under this umbrella to improve the academic experience of students through the application of principles taught in the course. An example of a project undertaken was campus transportation, to be made inexpensively and efficiently with minimal environmental and societal impact (i.e. on the surrounding neighborhoods); alternatives (automobiles, campus shuttle service, rental bicycles, walking) were assessed for convenience, cost to students and to the university, resources use, health/safety of students and impact on the larger community and the environment[18].

A variety of channels are used to disseminate student deliverables and increase campus community awareness about the STFS course. Various tours to local industrial sites were organized to observe sustainably-oriented practices; guest lecturers and panelists were invited to participate in the class discussions and help answer student questions. The final project presentations were made in a formal setting, using posters, brochures, power point slides, and videos. This project review showcase is made a public event with invitations to the entire campus community as well as all other stakeholders (industry visit hosts, potential employers, etc.) and hosted in the university's Main Administration building. During this event, the students present their findings and proposed solutions and their lessons learned from the course.

Numerous forms of student evaluations were also conducted. Concept mapping, at the beginning and end of the course, was carried out to assess student learning of concepts related to systems thinking and sustainability. Pre-concept knowledge (before students being introduced to course contents) and post-lecture quizzes were carried out and evaluated using a structured taxonomy to evaluate depth of knowledge on systems thinking and sustainability concepts [see[17] for a comparison]. In addition to the teacher course evaluations (discussed in section 5) at the end of the course, exit interviews were also conducted with selected students to collect their feedback for course improvement[17].

3. Challenges for Faculty

While the concept of team-taught multidisciplinary courses is very appealing, there are myriad challenges that must be overcome by a team of faculty to successfully develop and teach such a course. From the point of view of engineering faculty, the differing assumptions discovered among the faculty were a major challenge.

For example, sustainability issues ultimately involve a clash of stakeholders with differing values. No matter what the technical questions may be, ultimately it will become a question of policy and regulation, meaning the arena of politics, persuasion, marketing, lobbying and battling ideologies. This fact moves sustainability problems away from a purely technical arena into what are traditionally areas of the humanities classroom, such as the focus on understanding conflicting perspectives and ways of framing issues rather than determining which perspective is correct and rejecting the others as invalid. This shift is implied in the general consensus that addressing sustainability issues, which involve complex interactions—for example social and environmental systems acting on and changing each other—will demand an interdisciplinary approach both in research and in education, an approach for which a systems perspective is necessary[19]. The scholars responsible for the recent path-breaking Sustainability PhD program at RIT concur; to make real progress in developing curricula adequate to addressing sustainability issues means overcoming “the absence of a multi-faceted, interdisciplinary systems approach”[20]. Yet such a shift can seem, depending on one's discipline, to move a question from rigorous examination to a more trifling kind of consideration that leads to no particular result or to some mere fuzzy personal preference at best.

This issue tended to emerge indirectly and was usually discovered in different discipline-oriented assumptions and approaches to educational techniques, content interpretation, pedagogical tools, and evaluation. It seems now that faculty entered the project assuming that, while their subject fields were quite different, there would be general agreement on teaching matters since all were faculty at the same university teaching more or less the same kinds of students and expecting the same amount and kind of effort. This was not the case. The issue was that these were not always simply neutral differences of some mild interest but very troubling ones at times.

For example, one lesson learned was that engineering education may require quite a bit more rigor and highly deterministic analysis in its work, while marketing or design/architecture may emphasize more creativity and intuition with a different goal in mind. The former may stress proof reached only through quantitative means as its goal while the latter may stress as a goal effective persuasion to be reached through words or images. In the latter case, a rigorous mathematical proof would be irrelevant or even counter-productive. In the former case, it could be agreed that the persuasion was quite attractive yet without its having any value whatsoever. Thus for the faculty team a ticklish issue where during discussion of what should be expected of students doing an assignment, the possibility would arise of implying that a colleague's discipline was invalid or worthless. Added to this difficulty was the differing communication style of the disciplines. One of the authors, from a humanities background, can testify to the cautiously expressed disagreements during conference paper question and answer periods in that field, as compared to his first engineering conference, where the comments seemed, by comparison, extremely blunt, frank, outspoken, not to say rude. It took some time to see that those exchanges were actually amiable and good-humored, in fact quite a bit more so than the seemingly more polite ones in his former field.

This issue is presented first because it tended to complicate all the faculty team discussions during the first year, when the course was designed and run for the first time. Those discussions were focused mainly on three challenging areas:

<u>Content identification</u>: The main focus of the course was intended to be on the student team project work. One challenge therefore was to get the students up and running with enough background on sustainability and systems thinking in as little time as possible. Another danger here was sending the wrong signals about the course, which was intended to be active learning and student-led as much as possible, so there was a risk in beginning with something that might seem like traditional lecture to a passive audience. Faculty had to work out what was absolutely essential from their discipline and in how much detail, an especially tricky task during the development before the course had been taught for the first time. Used to thinking in terms of semesters, they had to think in terms of a few weeks or a few class hours. At the same time, they had to quickly teach each other about their disciplines, what would be needed in such a course and why, essentially make a case for their material. Thus, considerable discussion was necessary to reach a consensus not only about the topics that had to be covered but also about the depth of knowledge needed. Many sacrifices were required and faculty were always concerned about

ending up presenting a watered down and confusing version of their beloved subject. This part of course development requires much more out-of-class time and preparation by the faculty and also demands a willingness to rapidly learn enough about other disciplines to be able to judge competently what precisely gauged depth of the other disciplines would be needed and what would not.

Lack of time to become familiar with other faculty expertise and lecture content: A number of the faculty-related issues could be attributed to the limited time available for the faculty team to get to know each other's expertise, teaching style and lecture contents. A team of individuals who have collaborated on other efforts before would be ideal for a project of this nature. In practice, however, it is rare (if not outright impossible) to find faculty from four different colleges with prior experience working together. So was the case with the team working on this project; while some had collaborated before, others were new. This meant that, the faculty, too, had to go through the different phases of team development—forming, storming, norming and performing, as they are commonly known—for effectively teaching the course.

While the project officially kicked-off in the semester before the Spring 2012 (first) iteration of the STFS course and faculty team meetings were held regularly, the most focused faculty team interactions—and therefore the most intense team development—did not take place until very close to the beginning of the semester. The same thing took place in the second iteration, and the third has been the same, due to institutional constraints. Further, while course contents and the syllabus was agreed upon after considerable deliberations and individuals teaching each module were identified, there was not sufficient time for faculty to learn in advance about the exact contents of each other's modules. This led to the difficult situation of, for example, the individual teaching the fourth session having to wait for the person teaching the third session to complete his/her presentation to make sure there would be consistency and coherent flow between the sessions; constant revisions and editing of lecture content on-the-fly was required. This difficulty, however, was overcome by the second STFS iteration as faculty were more familiar with each other's content and a more collaborative approach to teaching (discussed in section 4) was adopted.

Again, the difficulty here was that the constraints overlapped with a ticklish area for any team: commitment and contributions. Sustainability (or sustainability science or sustainable development) is still somewhat a work in progress rather than an established discipline[21, 22]. This added to the project lead time and made the development of the course more time and work intensive, especially for those faculty with less background in the topics, that is, outside engineering. There was no brief introduction to systems thinking or to sustainability that seemed really satisfactory for faculty more or less new to the field so extensive reading and discussion was a necessity. At the same time, all faculty are constantly juggling deadlines, professional obligations and conflicting priorities. Thus, sometimes a comment or question during a meeting would indicate that someone was not up to speed on the material as yet. This would lead to unspoken suspicion. Was STFS first priority for everyone? Were the materials so painstakingly assembled and uploaded not being read? Were the entire faculty really fully engaged and keeping up with the work? These of course were impossibly awkward questions to raise among colleagues who were still to some extent strangers when the project began and thus they were not raised directly. Yet they are typical teamwork issues (as we are always telling the students) and need to be dealt with in some way (discussed further below in section 4).

<u>Expectations about student capabilities</u>: Designing the coursework meant making some judgments about what the students could and should be able to do. However, expectations are based on experience. Engineering faculty know what engineering students can be expected to do, much less about what other students can be expected to be able to do. But did they realize they didn't have a good basis for expectation? During the first year, the answer was no. It was assumed that the engineering student was the generic student for whom a course could be designed. In the same way, faculty from the other disciplines argued for and insisted on syllabus design based on expectations for what they knew their students could do, assuming their students were the generic student. The discussions during the syllabus design before first iteration were full of puzzling misunderstandings precisely because no one was clear about the differences in expectations for what the students could do or felt that the others were being too lenient (as opposed to realistic) or too demanding (as opposed to challenging). There was also the question of what the various groups of students felt it was legitimate to expect of them, a somewhat different thing. This of course led to some surprises.

Clearly, students coming from different disciplines possess a diverse set of knowledge, skills and abilities (KSA). While this is the exact scenario graduating students encounter in real life when joining a team in the workplace, and one the project aimed to emulate, developing a course based on expectations about students' capabilities, one where students from all disciplines can succeed, proved to be more difficult than expected.

In designing the course, the assumption was to assemble teams where each member had some useful skill from his or her discipline but no member had enough skills to do the entire project unaided. Thus, the project assignment involved more deliverables than a prototype or a cost-benefit analysis; making a video and a brochure to pitch the solution meant someone without analytical skills but with excellent digital video skills would be vital to making the project work. It was thought that this arrangement would combat any urge by the students to stay in the comfort zone and work only with classmates. For example, an engineering student is trained to use analytical tools following the rigor of precisely defining the system, following the set of physical laws and studying the simulation of system's evolution. This approach often uses a particular set of tools (e.g., software packages). A design or marketing student may not have these particular skills but may offer other sets of skills to evaluate the functionality or economic feasibility of the proposed solution or to understand how to pitch the solution to a client using digital media software tools. The difficulty for the student teams however turned out to mirror the difficulty for the faculty team. That is, whose discipline would determine when the solution had been achieved? That was a question of expectations. Students in a discipline have a sense by the time they are juniors or seniors of what is expected of a project and can usually tell the difference between bad, good enough, and very good. However, those expectations were not the same for all the disciplines involved, meaning that, for example, engineering students, used to putting in very long hours outside class, disagreed strongly with students in other disciplines who were satisfied with a more rapid intuitive solution they were confident was very good based on their own expectations and who felt the engineering students were being ridiculous over-achievers.

Luckily, these kinds of misunderstandings, once faculty are all aware of them, can be corrected in a second iteration. For example, the STFS faculty team was in agreement that a system dynamics tool for modeling and analyzing system behavior must be taught to enable students to assess the behavior of systems. In the first iteration of the course, a faculty member from Engineering taught the module (Vensim software), followed by recitation sessions conducted by the teaching assistants (both from Engineering). Faculty from all other colleges believed their students capable of learning Vensim to model system dynamics. However, while the engineering students succeeded, many students from the other colleges were not able to learn the application of the tool within the time available so the module was removed from the second iteration. Thus content identification for multidisciplinary courses that brings together students from different disciplines requires considerable deliberation and iterative review to be successful. It also requires willingness at times to sacrifice a useful topic or tool from one discipline in favor of making the course work for all the disciplines involved.

4. Challenges for Students

For undergraduate students accustomed to taking discipline-specific courses delivered by individual faculty, a multidisciplinary course team taught by a group of faculty from different disciplines can present various uncertainties: who is doing the grading? Who can answer my question authoritatively? To whom do I hand in an assignment or ask permission to hand in work late? This set of questions was an issue for the participating graduate students as well. Although the course was originally planned for upper level cohorts of undergraduate students—ideally juniors, as preparation for senior design and senior capstone project work—it attracted several graduate students and it was early realized that graduate students in the class might contribute to better diversity of skill levels and performance of the teams. On the other hand, their presence made for more difficulties in gauging the appropriate depth and breadth of the course content.

Difficulties with team work: One of the major goals of the STFS project was to increase students' abilities to be successful in multidisciplinary teams. Both the student teams and the faculty team (as discussed earlier) had their difficulties. Similar to faculty, student teams found it difficult to effectively work across disciplines, particularly when it came to the team project. Cultural differences between disciplines were found to influence team behavior. For instance, engineering students and design/architecture students expect and are quite used to long hours of work outside the classroom to complete assignments and projects in teams. However, business and education majors did not have the same expectations and did not consider them legitimate or reasonable. The latter consideration is important. The typical "free rider" team problem can be handled within a team because the guilty person will usually agree to contribute the required time if confronted carefully, meaning that he or she agrees at bottom that the requirements are legitimate. However, when team expectations were seen by some not as the legitimate course expectations but just as idiosyncratic overachieving by other students, faculty had to get involved in team disagreements, a less desirable approach.

A number of changes were introduced in the second iteration in an effort to overcome some of these difficulties. In the first run, faculty had delivered content presentations as solo efforts; in the second run, the presentations were done by two faculty lecturers, who therefore had to work out in advance what the content would be, what would be emphasized, and so forth. Although this approach was more work than doing a solo presentation, the preparation process helped the faculty better understand and appreciate each other's areas of expertise and clarify where the areas of disagreement were and what were only apparent disagreements. Students were able to witness faculty modeling ways to work together while in disagreement by finding areas of agreement and by working out a communication strategy in order to convey the necessary information without bogging down in the disagreement. It was clear from the student's exit interviews that this approach had a definite positive impact on student teamwork.

At the same time, teamwork was also made more visible as required work for the course. It had been intended as such but this was not clear during the first iteration so during the second iteration students were briefed on the difficulties to expect when working as a team and given strategies for coping, based on guidance in writing and revising a team charter to lay out roles and responsibilities. The charter was to be updated weekly based on project progress and posted online (on course management system) for review and feedback. Instructors and TAs made themselves available for coaching on how to get past team issues such as freeloading students who did not adequately participate or how to address issues where a single voice was too prominent[17].

Coping with an unconventional course: as much as team teaching was difficult for faculty, the model was also found to be challenging for the students. In a conventional course, students are used to learning from one individual, and can get used to the teaching style and standards of that person. They are used to focusing attention on one individual—the single instructor—as the provider of information.

The situation in the STFS classroom, however, was very different. While one (or two, in the second iteration) faculty delivered course content in each session, all faculty members present in the classroom participated in discussions when the floor was opened for questions and comments. The intent here was to provide the students with a more enriching experience and, sometimes, with diverse perspectives on how certain concepts are viewed by different disciplines. This model, where they must constantly shift attention between the instructors to follow the discussion, was new for the students and somewhat confusing.

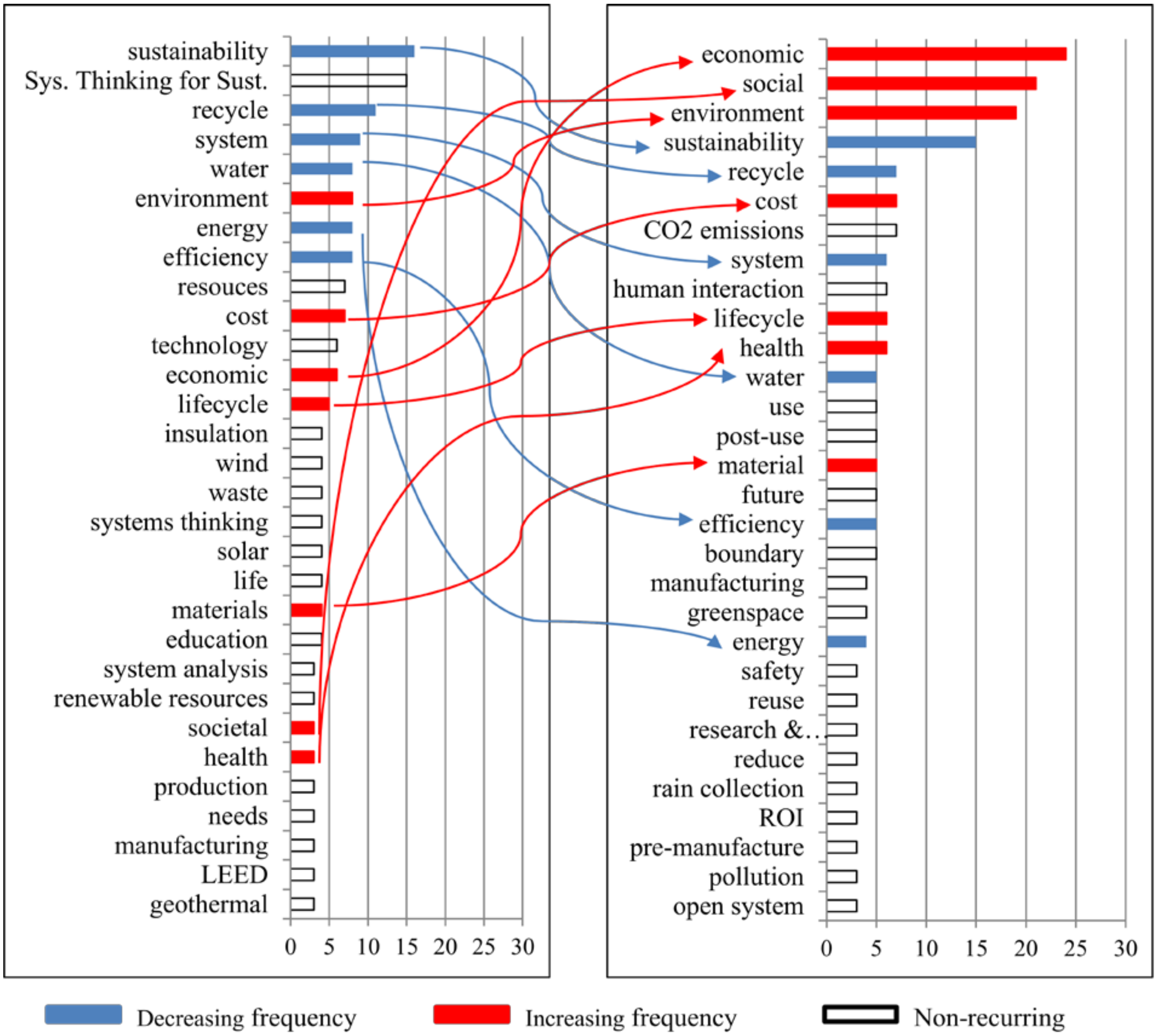
Something that came as a surprise to the faculty was that instructors in different disciplines have very different styles of teaching. Again the (false) assumption was that despite different subject matter we all do more or less the same thing in the classroom. Students indicated having trouble adapting to the different styles of teaching by the faculty, in part since the instructors doing the presentation changed from one session to another; they also expressed some difficulty getting used to the styles of teaching by faculty from other disciplines. For example, the use of notations and equations to clarify subject matter is very common in engineering. This, however, was found to be challenging especially for the business majors in the course. Again, faculty from design/architecture tend to use slides where the information is conveyed visually with little or no supporting text, something which was new to the engineering majors. These are inevitable aspects of team teaching courses even when they don't span disciplines and must be overcome to make multidisciplinary courses more attractive. The STFS faculty team has discussed several additional strategies, including the so-called "flipped classroom" approach in which video recording of multiple lecture modules are made available to students for viewing before the class so that class time can be used for enhancing understanding of the material and so that so that students can do repeat viewing and pausing to help them follow any difficult or complex multi-faculty discussions. This approach will be introduced in the third iteration (Spring 2014).

<u>Difficulties in synergizing concepts and assessments</u>: We discovered a significant difficulty for students when asked to think in the abstract specifically, when asked to define the system being considered. Students were expected to work toward understanding why defining a system is such a tricky task and why to a great extent a system is determined by who is doing the defining. This task is related to similar difficulties in defining sustainability, which, in the broadest sense, refers to a particular state of a system. The interesting aspect of sustainability, it was felt, is that it is a classic "wicked problem"—one which involves conflicting parties with conflicting goals and is not susceptible to solution that would be satisfactory to all in the same way that a problem in arithmetic is. These difficulties were designed into the course, in the sense that an appreciation for their difficulty would move students past a comfortable passivity that allows others to define what the problem is, such as in well-defined (therefore essentially unrealistic) homework

problems. In the first iteration of the course, the engineering students had something of an unfair advantage because they were able to see an approach to definition could follow from determining a system boundary, identifying all interactions across the boundary, providing a full description of constituents etc. This way of thinking was alien to the other students, however. To overcome this difficulty, the second iteration put more stress on the importance of definition, using a formative assessment to learn what students knew or thought they knew about basic concepts in the course, including "system" and "sustainability" and then after the first four weeks of intensive work on these newly introduced concepts, repeating the assessment.

The assessment of students' conceptualization has been performed by concept mapping evaluation. The chart shown in Figure 1 indicates the shift of understanding of the basic concepts found after the second course iteration. Systems thinking and sustainability are the highest ranked terms in the pre-concept mapping exercise rightly because these two terms were included in the course title; however, these are de-emphasized in the post-concept maps as the student's understanding of the concepts underlying these two broad terms has been widened; an appreciation for the conflicting goals to be managed for more sustainable solutions—economic, environmental and societal—is reflected in the post-concept maps with "sustainability" retained. The term "systems thinking" does not appear in the top 30 terms of the post-concept map and the term "system" is slightly reduced in number of occurrences with a more frequent identification of related terms such as boundary, human interaction and so on. These, while not evidence of student academic performance in the course, reflect the change in understanding of the complex concepts of systems thinking and sustainability. A few of these changes in the importance of terms in the concept maps is also reflected by the arrows in Figure 1. Note shifting of frequencies for the concepts either up the scale or down (color-coding is used for better visualization of changing frequencies). It is indicative that the most shifts up can be attributed to social aspects of the triple bottom line of the sustainability. Further study of the changes and a full account of this assessment analysis will be discussed elsewhere.

Different methods were used in the two previous iterations of the course to assess student learning. These include: teacher course evaluations (TCEs), formative assessment of basic concepts (using pre and post quizzes), pre and post concept mapping and exit interviews with students. The intent, particularly with the latter three methods, was evaluating the level of understanding of the multidisciplinary concepts and to use the information to assess, to the extent possible, whether teaching a multidisciplinary course to students from multiple disciplines together is more effective. A detailed discussion of these assessment tools is to be discussed in forthcoming papers by the faculty team; a brief review is presented in the following sections.



(a) Pre Concept Map (27 Maps) (b) Post Concept Map (22 Maps)

Figure 1: Pre and Post Concept Mapping Results from 2013 STFS Course

While several issues had to be addressed regarding the administering of TCEs (discussed in section 5), the student rating for teaching effectiveness in the first iteration was significantly lower than any rating each faculty usually received before for courses they taught individually. Student feedback also reflected the difficulties discussed throughout this paper; this input was useful when apprising course material and delivery effectiveness for modification, as needed, for the second iteration.

An important aspect of the assessment performed within the first two years of the project realization was a characterization of students' understanding of the key concept targeted by the learning objectives: sustainability. This characterization has been performed by using the Structure of Observed Learning Outcomes taxonomy[24, 25] (SOLO), aimed at understanding the levels of multi-structural conceptions of students prior to and after being exposed to instruction (using pre and post quizzes). SOLO analysis follows the five stages proposed by Carew and Mitchel (2002)[26], starting with pre-structural and ending with extended depths of knowledge levels. The results indicate a significant shift from the former to the latter. The key methodological drawback identified was the level of objectivity that can be achieved in the assessment of the knowledge levels, a judgment that inevitably depends on the lecturer's disciplinary background (four different colleges in our case). As a result of that consideration, a modified approach is being implemented for the third year (currently under way) by combining the concept mapping with SOLO taxonomy, hence increasing the deterministic approach to the depth of knowledge levels assessments. The results of this analysis (still ongoing) will be reported elsewhere.

Another on-going analysis uses the student responses to the pre and post concept maps in an attempt to assess the extent to which students in different disciplines broadened the understanding of the main concepts, and their interdependencies. For example, Figure 2 shows the number of course-related concepts students from different disciplines identified in the pre and post concept map (where ENG: Engineering, ARC: Architecture, BUS: Business & Economics, EDU: Education). The increase in the number of concepts identified in the post concept map, shown as a percentage, indicates that students from some disciplines learned (or at least remembered) a lot more. Further in-depth analysis with concept mapping results from all the previous iterations is on-going at the moment.

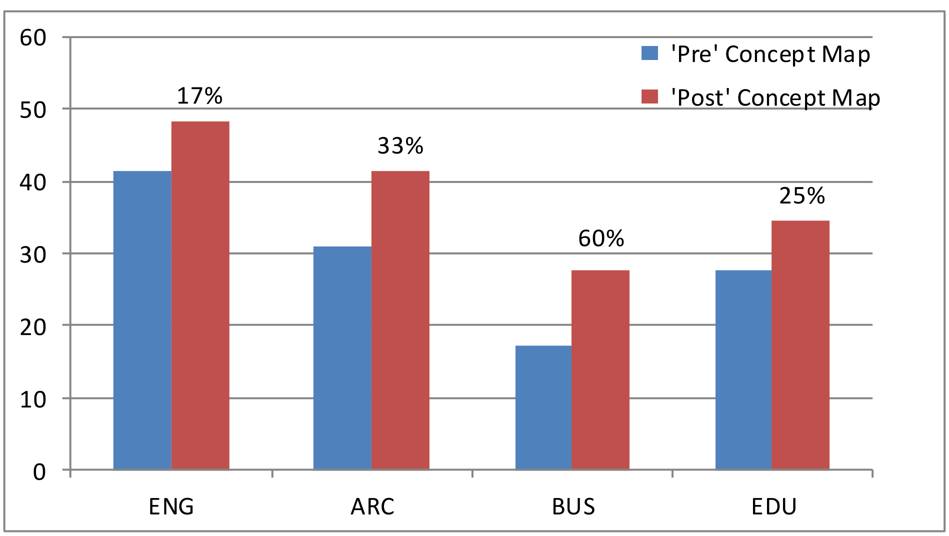


Figure 2: Discipline-based Assessment of Familiarity with Concepts

It must, however, be noted that none of these techniques allow evaluating whether team teaching a multidisciplinary course by a group faculty from different disciplines to students from different disciplines is better than the same team taught the course being delivered to each group of students separately (rather than having them in one group). While the general belief favors the former scenario, this cannot be evaluated without a 'control' group for comparison. The research team believes there could be an opportunity to address this question, though not completely, with the 2014 iteration of the course: one member of the faculty team is administering the course at the Texas A & M University to a group of Architecture and Design students using the same material developed by the faculty team for delivery at the University of Kentucky. This could be a potential 'control' group against which the assessment results from the multidisciplinary student group can be compared to evaluate the usefulness of the pedagogical model developed through this STFS course. These findings, too, will be included in a forthcoming publication by the research team.

5. Administrative/Logistical Challenges

Team teaching the STFS course presented a number of administrative and logistical issues that had to be overcome. While some of them were anticipated, others presented unexpected challenges that are still to be dealt with. These issues can be broadly classified into the following categories:

<u>Class schedule and classroom</u>: The first (Spring 2012) iteration was assigned to a classroom that turned out to be too large, so that students were too far from each other and from the instructors and there were audibility and visibility problems. The course was assigned three 50-minute class periods per week. The 50-minute sessions turned out to be too short, especially when students were working in teams on in-class activities and time needed to be saved for end-of-class presentations by the teams and for faculty feedback on their progress.

The second iteration (Spring 2013) shifted to two 75-minute periods per week in a smaller classroom whose desks were easily moved into different configurations. This change provided a weekly rhythm for the first month: faculty presented content in the first class of the week and in the second class of the week, students discussed, asked questions and practiced using the material presented. The "application" class was also an introduction to an assignment due a few days later, where students were expected to demonstrate understanding of the week's material.

Thus, in this run of the course, students felt better prepared to tackle each assignment because the practice/discussion sessions deepened the lessons learned in the faculty-led lectures. After the first five weeks of content presentation, faculty assigned students to teams, and the students selected their team projects. Hereafter, the first class day of the week was used to present relevant skills for their showcase projects now underway—for example, team dynamics, issues in survey design, and so forth. Students saw how the course assignments prepared them for the team projects because in this iteration the outcomes from the last year's student projects were available to be displayed and explained during the first week of class, giving students a sense of where they were going and what skills or approaches they might need to get there[17].

Communication (no single point of contact): Less serious but still troublesome were issues such as who the students should contact with concerns or questions outside of class and how the flow of duplicate cc'd emails between students and instructors could be kept to a minimum. While it may seem minor, this uncertainty about the point of contact for communication made the students unnecessarily uneasy with the team-taught format. When emails were cc'd by students to all faculty, and sometimes to both TAs as well, there was also a question of which one of the faculty should respond first; the uncertainty often led to delays in responding to student concerns. A relatively simple adjustment in the second iteration, making one faculty member the point of contact for all administrative student emails, solved this problem but only partially. Students continued to direct subject matter-related emails to relevant faculty. A more troublesome issue was helping students quickly master an unfamiliar platform (OpenClass) that faculty were not necessarily familiar with either. This guaranteed a certain level of frustration for everyone, with problems logging on, problems uploading assignments, suspicion that these problems were versions of "dog ate my homework," faculty unable to help students since faculty had their own issues with the platform, etc.

Evaluation and other faculty-related administrative issues: Faculty eager to work out the intriguing conceptual aspects of a team-taught course can be tripped up by difficulties coming at them from this not-so-intriguing area. Yet in many ways this was a critical area for the success or failure of the STFS effort. That's because there were issues that complicated enrollment and registration, meaning the course might have trouble establishing itself as a regular part of the curriculum, and there were issues with teacher evaluation and faculty distribution of effort that penalized rather than rewarded faculty who participated in the project.

There were a number of issues to resolve concerning how teacher evaluations would be done (a separate evaluation for each instructor? a combined evaluation of all instructors?) and how students from different colleges could register for the course. In the end the course was registered as an Engineering course (ME599, Mechanical Engineering and MFS 599, Manufacturing Systems Engineering) with cross-listings in Marketing (MKT 390) and in Architecture (ARC 599). A complicated set of requirements in the College of Education meant those students could not register in a straightforward way without losing a key elective and so had to enroll in the course under one of the other college's listings. To avoid the confusion of students having to complete multiple evaluation forms, one for each instructor, it was decided that a single teacher course evaluation will be given. While this is less complicated administratively it sacrificed an important aspect of teacher recognition and evaluation for administrative convenience.

The most serious of the faculty-related administrative issue was difficulty in having a team-taught course recognized for faculty distribution of effort (DOE). This was especially true for junior faculty coming up for tenure. None of the faculty involved in the project received credit in their DOE for teaching the course, which they all undertook as an additional responsibility over and above their normal teaching load. But the coursework was not divisible by four. Those who have never taught such a course might assume that it involved 1/4 of a course. However, especially for a new course never offered before, the effort by each faculty member was actually close to a full course for each instructor. The course involved curriculum development time in summer and fall for extensive discussions of possible assignments and syllabus revisions; during spring, in addition to attending almost all the sessions, whether presenting or not, the faculty met weekly, spent time coordinating the assignments and presentations, shared grading and office hours. In addition, faculty also had to master the material from the other disciplines. Not only does this add an un-credited invisible course overload to faculty, it is not helpful for morale since it suggests that mounting such an ambitious interdisciplinary effort is not of value to the department or the college. This is a challenge that has yet to be administratively resolved[27].

Gaining the same level of support from all colleges involved in delivering multidisciplinary courses such as STFS can also be challenging. This can not only affect resource availability to teach such courses but also influence faculty willingness to invest time and perhaps career chances on a rather risky project that can bear negatively on their performance evaluations. Due to the problem-based approach to learning adopted in this course and the numerous activities incorporated for this purpose, teaching assistant support was to be granted by all four colleges involved. However, only the College of Engineering was forthcoming in providing TA support for the course. While this support was essential to course delivery, TAs from Engineering are likely to have discipline bias as well; a more diverse pool of TAs could help provide the students the diverse and multidisciplinary orientation necessary in a course such as STFS. It is also vital that Chairs and Deans of all faculty engaged in such multidisciplinary teaching efforts are aware and appreciative of their contributions. Otherwise, involvement in projects such as these can be detrimental, particularly to junior faculty who are on the tenure-track path.

6. Conclusions & Lessons Learned

For those who might be considering a project along the lines of STFS, we offer the following in case they might be useful.

1. Expect the inevitable surprises

It may not be possible in designing such a complicated project to avoid the misunderstandings that resulted from the very different assumptions and expectations that came from combining four very different disciplines. These misunderstandings only became clear after the difficult first iteration was completed. Looking back, we might suggest laying the groundwork for such a course by first offering one or two courses involving only one or two disciplines at first as a way to prepare faculty to work together on something eventually involving four disciplines. This would also help the staff in the colleges (advisors, for example) learn how best to work together as well. It's also possible that faculty professional development, perhaps a summer workshop, would have been good groundwork for the project.

2. Be high profile

It turned out that, due to considerable work from the design/architecture faculty member, the STFS project showcase attracted the attention of the university president, who came to the showcase, stayed for the presentations, and then loudly sang its praises since it aligned with a university priority of his to offer unique multidisciplinary courses. His interest is expected to be very helpful to the STFS project as we work out the administrative problems which are difficult to address at the department or even at the college level. Note that this was an unexpected benefit to having on the faculty team a member from a discipline with expertise in dazzling persuasive presentations to clients.

3. Seek out campus resources

Not until the second iteration did we discover a campus resource that worked like a drop in writing center but was focused on digital media and could assist students with Power point and video critique and improvement. This not only was appreciated by the students, who had skills but doubted their expertise, but it helped give the project deliverables—used for dissemination on campus, and perhaps elsewhere—a high profile.

4. Student Tracking

This is a major weakness in the project we are still working on: how best to track student activity so as to measure learning and identify difficulties, ideally by using whatever platform the students used to communicate and to upload assignments. This is something that should have been in place early. The course management system was used to monitor student progress, in terms of turning is assignments or falling back, and provide regular alerts. However, the collaboration space within such systems could be used to also to monitor team progress. Looking back, we would say that probably there needed to be another member of the team (or perhaps another campus resource) whose expertise was in this area.

In conclusion, the authors would like to clarify an important point about STFS. The paper presented here deliberately focuses on the difficulties encountered, especially during the initial design, the first course iteration, and the somewhat rueful reflections and discussions following that iteration, ones that led to the much more successful second iteration. But that may leave the wrong impression about the project as a whole. It's a mistake to assume that because the mechanics come out from under the car dirty and grease-stained, with clothes torn and knuckles bruised, the repairs failed. On the contrary, the repairs were successful and the engine is running very well as we begin iteration 3. The faculty team has moved past its initial awkwardness to a more comfortable working relationship where responsibilities have been allotted more naturally according to people's strengths. The syllabus has been revised successfully to deal with difficulties students encountered in iteration 1. The students in iteration 2 gave very positive evaluations of the course and the instructors; two in fact were so interested in their project that they continued to work on it over the summer. Other institutions, in the U.S. and abroad have expressed interest in adopting the STFS approach; to pursue that, the team is currently engaged in working out a way to teach iteration 3 to multiple classrooms in widely separated locations at the same time.

In conclusion, it must be noted that the authors' intention with this paper was to share the discoveries from the STFS project from the perspective of engineers collaborating with other disciplines to deliver complex curriculum content and how to make such efforts more successful. Detailed discussions about STFS project, syllabus revisions as well as more insights about the achievements are available in other papers from the STFS team[17, 18, 23].

Acknowledgements

This work was supported in part by the U.S. National Science Foundation under Grant TUES 1044232. The authors wish to acknowledge the other members of the STFS faculty team [Prof. Gregory Luhan (College of Design and Architecture), Prof. Leslie Vincent (College of Business and Economics) and Prof. Margaret Mohr-Schroeder (College of Education)] for their professional expertise, hard work, insightful contributions, endless patience and good humor during the STFS project.

References

1. National Academy of Sciences, Facilitating Interdisciplinary Research, 2004.
2. Members of the 2005 "Rising Above the Gathering Storm" Committee , Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5; Prepared for the Presidents of the National Academy of Sciences, National Academy of Engineering, 2010
3. Gordon E, The Global Talent Crisis. The Futurist, 43(4) Sept/Oct: 34-39, 2009
4. World Economic Forum, (2013) The Global Competitiveness Report 2012-2013. Retrieved from http://reports.weforum.org/global--competitiveness--report--2012--2013/
5. Reinventing Undergraduate Education: A Blueprint for America's Research Universities, Boyer Commission on Educating Undergraduates in the Research University, 1998.
6. National Research Council, From Analysis to Action: Undergraduate Education in Science, Mathematics, Engineering, and Technology, Report of a Convocation, Washington, DC: National Academy Press, 1996.
7. National Science Foundation, Shaping The Future: New Expectations for Undergraduate Education in Science, Mathematics, Engineering, and Technology, 1996.

8. National Research Council, Improving Undergraduate Instruction in Science, Technology, Engineering and Mathematics. Washington, D.C. National Academies Press, 2003.
9. Transforming Undergraduate Education in Engineering, Phase 1: Synthesizing and Integrating Industry Perspectives, May 9-10, 2013.
10. Criteria for Accrediting Engineering Programs Effective for Evaluations During the 2012-2013 Accreditation Cycle, Accreditation Board for Engineering and Technology (ABET), pp. 5.
11. Smil, V., Energy in Nature and Society: General Energetics of Complex Systems Cambridge: MIT Press, 2008, pp. 359.
11. Rittel H. and Webber M., Dilemmas in a General Theory of Planning, Policy Sciences 4, 1973, pp. 155-169.
12. Seager, T. P. and Selinger, E. Experiential Teaching Strategies for Ethical Reasoning Skills Relevant to Sustainability. Proceedings of the 2009 IEEE International Symposium on Sustainable Systems & Technology (ISSST) and 2009 IEEE International Symposium on Technology and Society (ISTAS). May 18-20, 2009, Tempe, Arizona, 2009.
13. Foster, J, Kay J and Roe P., Teaching Complexity and Systems Thinking to Engineers. 4thUICEE Annual Conference on Engineering Education Bangkok Thailand, 2001.
14. Greadel T.E., Managing Human-Environmental Systems for Sustainability, The ultimate Systems Problem, CID Working Paper No. 196, Harvard University, 2009, pp. 147-156.
15. Kaufmann, D.I., Jr., Systems One: An Introduction to Systems Thinking, Future Systems, Inc., Minneapolis, 1980.
16. Meadows D, Thinking in Systems: a Primer, edited Diana Wright, 2008
17. Badurdeen, F., Brown, A., Gregory, R., Fu, H., Schroeder, M., Sekulic, D., Vincent, L. and Luhan, G.A., Reframing Interdisciplinary Approaches to Systems Thinking for Sustainability, Proceedings of the International Symposium on Sustainable Systems & Technologies, May 15-17, Cincinnati, OH, 2013,
18. Badurdeen, F., Gregory, R., Luhan, G.A., Schroeder, M., Vincent, L.V and Sekulic, D.P., Systems Thinking for Sustainability: Envisioning Trans-disciplinary Transformations in STEM Education, International Symposium On Sustainable Systems & Technology 2012, Boston, MA, May 16-18, 2012, pp. 1-6.
19. Warburton, K., Deep learning and education for sustainability, International Journal of Sustainability in Higher Education, Vol. 4 No. 1, 2003, pp. 44-56.
20. Stiebitz, P., Seagar, T., Babbitt, C., Gaustad, G. and Nasr, N., Curriculum Development for the Sustainability PhD Program at RIT. Proc. of the 2010 International Symposium on Sustainable Systems and Technology. Washington, D.C. May 17-19. 2010.
21. Levin, S.A., Clark, W.C. Eds, Toward a science of sustainability: Report from Toward a Science of Sustainability Conference, Airlie Center, Warenton, VA. CID Working Paper No. 196, Center for International Development at Harvard University, May 2010.
22. Bakshi, B. R., Gutowski, T.G., and Sekulic, D.P., Thermodynamics and the Destruction of Resources, Cambridge University Press, Cambridge, UK, 2011, pp. 477-488.
23. Luhan, G. and Gregory, R., Across Disciplines: Triggering Frame Awareness in Design Education presented at the XVII Congreso de la Sociedad Iberoamericana de Grafica Digital Conference - SIGraDi 2013, November 20-22, 2013, Valparaiso, Chile, 2013.
24. Biggs, J.B. (ed), Teaching for Learning: the View from Cognitive Psychology, Hawthorn, Victoria, 1991.
25. Biggs, J.B. and Collis, K.F., Evaluating the Quality of Learning: The SOLO Taxonomy, Academic Press, New York, 1982.
26. Carew, A.L. and Mitchell, C.A., Characterizing undergraduate engineering students' understanding of sustainability, European Journal of Engineering Education, Vol. 27, No. 4, 2002, pp. 349-361.
27. National Academy of Sciences. Facilitating Interdisciplinary Research http://www.nap.edu/catalog/11153.html, Accessed on May 05, 2013.