AC 2010-1451: DEVELOPMENT AND DISSEMINATION OF LEARNING SUITES FOR SUSTAINABILITY INTEGRATION IN ENGINEERING EDUCATION

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Abstract

As pointed out in a key presentation in “Sustainability and Engineering Programs” within the Environmental Engineering division at the 2008 ASEE conference, one of main challenges for incorporating sustainability into engineering education is the lack of effective learning materials. The work presented here is based on a project funded by the National Science Foundation that focuses on addressing those challenges by creating effective learning materials and demonstrating successful new teaching strategies. The paper begins with a brief overview of the entire project and then focuses on the development of learning suites and dissemination of such suites through a workshop. The learning suites have been designed according to the Fink’s taxonomy of significant learning and research from the learning sciences. The paper introduces the learning suites and discusses how to use the Fink’s taxonomy and other research to guide the development of learning objectives and activities for integrating sustainability into engineering education.

The use of these learning suites was introduced in a workshop format at the Association of Environmental Engineering and Science Professors Conference in 2009. The paper describes the design of the workshop using the learning science principles and discusses the assessment of the workshop.

Introduction

Engineering education in the 21st century is very complex; not only because of the “grand challenges” posed for engineering itself as developed by the U.S. National Academy of Engineering (Table 1) but also from the declining proportion of students choosing engineering as a profession and the lack of diversity represented in the remaining students. Examination of the grand challenges in Table 1 suggests the complex technological nature of the individual and combined challenges as well as the importance of considering sustainability issues. The reaction by many engineering educators to solve such problems in the classroom would be to immerse students in traditional methods of developing new technology or application of existing technology to the problem. In this process students would not typically integrate issues of society, economy, and environment into their solution.

Table 1. Grand Challenges for Engineering (NAE, www.engineeringchallenges.org)

<table>
<thead>
<tr>
<th>Make solar energy economical</th>
<th>Engineer better medicines</th>
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<tbody>
<tr>
<td>Provide energy from fusion</td>
<td>Reverse-engineer the brain</td>
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<tr>
<td>Develop carbon sequestration methods</td>
<td>Prevent nuclear terror</td>
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<tr>
<td>Manage the nitrogen cycle</td>
<td>Secure cyberspace</td>
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<tr>
<td>Provide access to clean water</td>
<td>Enhance virtual reality</td>
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<tr>
<td>Restore and improve urban infrastructure</td>
<td>Advance personalized learning</td>
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<tr>
<td>Advance health informatics</td>
<td>Engineer the tools of scientific discovery</td>
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We believe the “grandest challenges” for 21st century are actually global social, economic, and environmental challenges, defined by stressors such as: population, urbanization, consumption, water scarcity, and climate change. Sustainable engineering\textsuperscript{a} is one approach to solve such challenges. Mihelcic and Zimmerman\textsuperscript{3} state that “It is through new scientific, technological, and policy innovation that we can maintain economic prosperity while also improving the quality of life for our citizens. This goal of creating and maintaining a prosperous society needs to be met without the negative impacts that have historically harmed our natural resources, the environment, and communities. This requires a new perspective and new understanding of the environmental damages that have been traditionally associated with development.”

To help students achieve this new perspective and understanding required to meet these grand challenges, educators must understand that engineering solutions will not be solely technology based and not applied uniformly to what may seem at quick glance to be similar problems. Technology must be appropriate for the given geographical, environmental, cultural, social, political, and economic setting, it must be developed to consider potential social and environmental impacts, and importantly, it should be implemented by individuals who understand the critical importance of solving problems at the technology/human interface. And importantly, sustainability must also be incorporated into all steps of engineering design.

Integrating sustainability into engineering education will enable students to meet those grand challenges and may also increase the recruitment and retention of women and underrepresented groups in engineering. Data suggested that young women and men are not choosing careers in engineering in part because this profession is perceived to lack a connection to helping improve the world around them\textsuperscript{4}. Although serving humanity is at the heart of the engineering profession\textsuperscript{5}, the engineering education system and infrastructure (texts, learning aids, faculty development) have largely lost this core connection. Sustainability education with its holistic nature of technology that is combined with human dimension will re-establish the sense of this connection. There is some indication that sustainability also contributes to the increase in recruiting and retaining traditionally underrepresented groups in engineering\textsuperscript{6}.

Sustainability integration may be difficult for many college and university graduates of science and engineering programs because typical educational learning outcomes for engineering are based on foundational knowledge and application; i.e., graduates should remember information and ideas and subsequently apply this knowledge to problems. There are some other challenges for such integration; for example, resistance to change from engineering curricula with an emphasis of economic cost/benefit analyses\textsuperscript{7}, strict disciplinary/departmental setting which is a barrier for highly interdisciplinary research and education\textsuperscript{8}, and lack of resources\textsuperscript{9}.

One of main challenges for incorporating sustainability into engineering education is the lack of effective learning materials that add learning outcomes related to \textit{caring} and the \textit{human dimension} (as defined by Fink\textsuperscript{10}) to typical educational learning outcomes. Caring means that students develop new feelings, interests, and values. The human dimension means a student

\textsuperscript{a} defined here as the design of human and industrial systems to ensure that humankind’s use of natural resources and cycles do not lead to diminished quality of life due either to losses in future economic opportunities or to adverse impacts on social conditions, human health, and the environment\textsuperscript{2}.
learns about oneself and others. This is critical if a balance of societal issues is to become inherent in engineering education and practice.

**Overview of CCLI Project**

This paper is based on a research project funded by the National Science Foundation which is creating effective learning materials for sustainability and proving the effectiveness of new teaching strategies. Several key elements in the project include: 1) implementing and disseminating an innovative textbook that introduces sustainability into the civil and environmental engineering discipline, 2) creating and disseminating learning suites that can be used by faculty in other disciplines to introduce sustainability into their fundamentals discussions, 3) implementing a green engineering course at partner universities and educational innovations in the form of student-to-student networks between partner universities, 4) developing faculty expertise through faculty workshops and faculty-to-faculty networks, and 5) assessing those transformational learning practices and peer-to-peer networks.

The project has been running for two years. The textbook *Environmental Engineering: Fundamentals, Sustainability, Design*³ was published by John Wiley and Sons and released in July 2009. The book is 695 pages and has individual chapters on 1) sustainable development and 2) green engineering. The green engineering course has been implemented in Yale University and will be offered simultaneously at the University of South Florida in spring 2010.

The introduction of the textbook and green engineering course was presented in 2008 at the ASEE annual conference. Several learning suites have been created and disseminated. This paper focuses only on the development of the learning suites and dissemination of the first two suites through a workshop held in summer 2009. The paper describes both the design of the workshop and assessment of the workshop. Here we introduce the learning suites and discuss how to use Fink’s taxonomy and other research to guide the development of learning objectives and activities to integrate sustainability into engineering education. The learning suites have been designed according to the Fink’s taxonomy of significant learning and research from the learning sciences. The suites include: 1) Fink taxonomy framework and guiding questions for developing learning objectives; 2) learning objectives for all six areas of development in the Fink taxonomy; 3) activities appropriate for individuals or groups; 4) an editable power point presentation with notes for faculty, and 5) assessment activities that an instructor can assign to individual students or to groups to determine if they have achieved the learning objectives.

**Introduction of Fink’s Taxonomy**

Fink’s taxonomy is a new “taxonomy of significant learning” developed by Dr. L. Dee Fink.¹⁰ There are six major categories in this taxonomy as shown in Figure 1 and described below.

- **Foundational knowledge**: students understand and remember information, key ideas or perspectives.
- **Application**: students engage in various thinking (critical, creative, and practical), develop important skills, or learn how to manage complex projects.
- **Integration**: students recognize and make connections among information, ideas, perspectives, personal, social and real life.
- **Human Dimension**: students learn about themselves and understanding and interacting with others.
- Caring: students change in their feelings, interests and values.
- Learning How to Learn: students learn about how to be a good student, engage in inquiry and construct knowledge and eventually become a self-directing learner.

![Fink Taxonomy of Significant Learning](image)

**Figure 1.** Fink Taxonomy of Significant Learning

A detailed guide of applying Fink’s taxonomy can be found in L.D. Fink’s book, *Creating Significant Learning Experiences*. In summary, Fink advocates that faculty begin by determining what information, abilities, or views that they want the student to possess in two or three years after the course is finished. This approach, which uses a long-term time frame, differs from typical course design where the instructor asks what they want the student to know at the end of the course. With a longer horizon, the instructor is forced to reflect on what knowledge, abilities and perspectives are important enough to transcend the artificial confines of the course. Fink’s six categories of development serve as a framework for reflecting on what one wants the students to retain at the future point in time.

**Development of Learning Suites**

Learning suites are being developed in the following areas: 1) Sustainable Development, 2) Systems Thinking, 3) Population, 4) Water, and 5) Energy. We developed the learning suites
according to the process recommended by Fink\textsuperscript{10}, which involves: 1) understanding the important situational factors in learning situation, 2) creating significant learning goals, 3) designing feedback and assessment, and, 4) developing learning activities and lecture material.

**Understand Situational Factors:** To identify important situational factors, information was compiled as recommended by Fink\textsuperscript{10}. This includes specific factors in learning situation (e.g., number of students, level of students, length and frequency of learning, delivery methods), expectation of external groups (e.g., societal needs, state or related professional societies accreditation requirements, institution or department curricular goals), nature of the subject (e.g., convergent or divergent, cognitive or physical skills, stable or rapidly changing), characteristics of learners (e.g., life situation, professional goals, prior knowledge and skill, learning style), characteristic of teachers (e.g., prior experience, competence in the subject), and special pedagogical challenge. Since the learning suites are intended to be materials that faculty can easily insert into an existing course(s), each suite was designed for three-hours of in-class time (i.e., a one-week class period in a common class setting or common length of a workshop).

**Create Learning Goals:** Before formulating significant learning objectives, an important question has to be asked; “what impact do I want this learning experience to have on students, that will be there a year or more after the learning is over?” Traditionally when a faculty member creates learning materials, the question in their mind is: “what knowledge do I want students to learn or know?” However, the learning goals of Fink’s Taxonomy focus on the impact of learning on a student’s life instead of merely acquisition of information. For this project, we created the significant learning goals by following the guiding questions for each category of Fink Taxonomy as shown in Figure 1 (e.g., “what connections should a student recognize and make between materials in this course and the students’ own personal, social, and work life.” under the category of Integration). These guiding questions help the class designers of the learning experiences think in a different mindset. A sample of significant learning goals that were used to guide the development of the learning suite for “Sustainable Development” is provided in Table 2.

**Table 2. Significant Learning Objectives Developed to Guide the Creation of the Learning Suite for “Sustainable Development”**

<table>
<thead>
<tr>
<th>Foundational Knowledge</th>
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<td>1.1</td>
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<tr>
<td>1.7</td>
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<td>1.8</td>
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</table>
well-being for all and 2. sustainability of environmental integrity, and 3. the ratio of the two, which measures the efficiency of converting natural capital to real human well-being;

1.9 | Understand that sustainable solutions rely on local resources;
1.10 | Understand that Sustainable development implies a shift in thinking from “economy of scale” to “economy of scope”

### Application

2.1 | Identify appropriate sustainable development indicators for a system;
2.2 | Select the right method to evaluate the sustainability of products, processes or services from system perspective;
2.3 | Define a design problem from a systems view (e.g., The need to relocate an company’s office buildings may be more of an issue of transmitting information instead of creating a new location for people to meet);
2.4 | Identify leverage points within a system that can serve to make the system more sustainable;
2.5 | Create innovative solutions (strategies, designs, consumption patterns, policy) that have the potential to make the system more sustainable based on system analysis;
2.6 | Learn to set sustainable development goals and select appropriate indicators and methods to monitor sustainability performance of a system;
2.7 | Learn how to manage community sustainable development projects with application of all above thinking.

### Integration

3.1 | Through research, determine how natural systems and social systems are linked to one another through stocks and flows;
3.2 | Recognize the connection between sustainable development and topics such as system thinking, population, water, material and energy;
3.3 | Identify sustainable indicators that have a local and global relevance;
3.4 | Relate the concept of sustainable development to their own behavior and decisions;
3.5 | Develop a set of sustainable development indicators for their lives;
3.6 | Describe the importance of environmental integrity (species diversity, health of ecosystem) to real human well-being.

### Human Dimension

4.1 | Understand both sides of the sustainable development balancing equation (capacity of the natural system and demands of the social system) can be altered significantly by human actions and their impact on the local environment, global environment, and community;
4.2 | Understand their role in sustainable development;
4.3 | Understand that one’s own view of the world results from mental models where facts are ascribed personal meaning only represents part of the whole situation and is biased by one’s mental models;
4.4 | Appreciate others’ views on sustainability and see a situation from another’s perspective;
4.5 | Sustainable solutions require the consideration of all peoples’ aspirations and the collaboration with others;
4.6 | Awareness and reflection on mental models facilitates sustainable design.

### Caring

5.1 | Feel they are important and “part of the solution” for sustainable development;
5.2 | View the field of engineering as one of tackling challenges caused by the global economic system (i.e., as a field with a high human purpose);
5.3 | Value the perspectives brought by other disciplines in solving sustainable development challenges;
5.4 | Care about their community (e.g., campus), environment.

### Learning How to Learn

6.1 | Familiarize with Internet resources related to local and global issues of sustainable development;
6.2 | Identify a problem related to sustainable development in their community that they have a passion;
6.3 | Identify resources to get information for solving the problem from 6.2;
6.4 | Solve the problem by synthesizing information found through self-directed learning in 6.3;
6.5 | Practice the virtues of inquiry and critical thinking when evaluating new information: Intellectual integrity; Intellectual humility; Confidence in Reason; Intellectual Perseverance; Fairmindedness; Intellectual Courage; Intellectual Empathy; Intellectual Autonomy;
6.6 | Develop a metacognitive awareness of their own thinking process (how their biases enter in the selection of data and reasoning).
**Design Assessment:** We designed the assessment activities within the modules based on Fink’s recommendations for what are called “educative assessments”\(^\text{10}\). Educative assessments are intended to assess what a student will be able to do in the future within the context of an authentic (or “real world”) challenge. Fink contrasts “educative assessments” with what he calls “auditive assessments,” which normally ask the learner to reproduce what they have learned in the past. The characteristics of educative assessment activities are that they:

- are realistic in what the learner might encounter in an authentic challenge;
- require judgment and new thinking;
- ask the student to do the subject;
- replicate or simulate the contexts in which adults are tested in the workplace, in civic life, and in personal life;
- assess the student’s ability to use a repertoire of knowledge and skill efficiently and effectively to negotiate a complex task;
- allow appropriate opportunities for students to rehearse, practice, consult resources, and get feedback on and refine performances and products.

**Develop Learning Activities and Material:** The learning activities were developed based on active learning. In a passive learning mode, students merely receive information; however, in an active learning environment, students learn by getting information, experiencing (doing and observing) and reflecting. Some activities promote active learning, such as case studies, classroom discussions, role-play, and term papers. As mentioned previously, each suite was designed for three-hours of lecture time, most of learning actives focus on classroom discussions which students learn by doing. For each learning activity, targeted learning objectives were identified. An example of one specific learning activity is shown in Figure 3.

![Figure 3. An Example of Learning Activities for Sustainable Development](image)

PowerPoint slides have been developed for each learning suite. Most of the foundational knowledge is covered through lecture; however, many slides also include in-class activities to...
actively engage students in classroom. In the notes contained in each slide, the specific learning objectives are identified and the source for additional information is provided. To design those slides in an appealing way, a professional graphic designer has been involved in the team to make the slides more visualizing and friendly to learners. An example of one slide in the learning suite of “Sustainable Development” is shown in Figure 4.

![Slide Example](image)

**Figure 4.** An Example of a Slide for the Learning Suite of Sustainable Development.

As described above in the development of learning suites, learning objectives, assessment activities, learning activities and lecture materials are closely integrated together. Learning objectives are embedded in lecture materials and assessment and learning activities.

**Dissemination of Learning Suites**

**Content of Learning Suites:** Two learning suites (Systems Thinking and Sustainable Development) have been developed as stand-alone educational materials for engineering educators of all fields. They also support the textbook *Environmental Engineering: Fundamentals, Sustainability, Design* with references to areas where faculty can delve deeper into subjects. The development of those learning suites was described before. Each learning suite includes the following:

- Learning objectives for all six areas of development in the Fink taxonomy (Foundational Knowledge; Application; Integration; Human; Caring; Learning How to Learn)
- At least three “Activities” were developed for individual or group work. Each activity includes targeted learning objectives, a profile of the learning activity itself (time investment, type of learning, Fink areas of development that it focuses on), standards for grading, performance criteria, and notes for faculty.
- An editable power point presentation with notes for faculty that are also tied back to the textbook.
- At least three “Assessment” activities that an instructor can assign to individual students or to groups to determine if they have achieved the learning objectives. Each includes: targeted learning objectives from the Fink taxonomy, performance criteria and standards for grading.

**Dissemination of Learning Suites:** We introduced the use of these two learning suites in a workshop format. Our three-hour workshop on how to use the learning suites was first presented at the Association of Environmental Engineering and Science Professors Education and Research Conference on July 26, 2009 (Iowa City, Iowa). There were 20 workshop participants who worked within teams of four to five people. Our goal for the workshop was to expand the participants’ capacity to integrate sustainable development design principles into existing courses. Our objective was to introduce the pedagogical framework and tools within the learning suites. The strategy was to empower participants through guided practice, true to the workshop format.

Our intent in conducting the workshops was to enable faculty to experience using the learning suites in a way that would encourage them to pick and choose how they might adopt or adapt the materials for their specific courses. The electronic versions of presenter slides are editable so that they can be customized.

Table 3 below details how the workshop was structured. All activities and materials presenting within the workshop were taken from our first two learning suites. We designed the workshop to minimize the cognitive load on the participants. Most activities were 20 minutes or less to allow participants to “reset” their attention for each activity interval.

**Table 3. Schedule for the three-hour workshop.**

<table>
<thead>
<tr>
<th>10 minute intervals</th>
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<tbody>
<tr>
<td>Introduction</td>
</tr>
<tr>
<td>Self-Assessment-28 item questionnaire</td>
</tr>
<tr>
<td>Fink Taxonomy &amp; Learning Activity design principles, sustainability principles</td>
</tr>
<tr>
<td>Using the Fink framework-creating significant learning outcomes</td>
</tr>
<tr>
<td>Review individual assessments</td>
</tr>
<tr>
<td>Break</td>
</tr>
<tr>
<td>Group work using “learning activities” from the suites</td>
</tr>
<tr>
<td>Select Groups Report out results - Ideally, we chose one group from each level to report results for 5 minutes each.</td>
</tr>
<tr>
<td>Summary - text, tools, labeling, assessment</td>
</tr>
<tr>
<td>Workshop evaluation</td>
</tr>
</tbody>
</table>

**Workshop Evaluation Results and Discussion**

Of the 20 participants, 18 completed the workshop survey. Workshop participants (18) for the Learning Suite materials had an overall very positive response to the workshop, ideas and
materials presented in the workshop. The following five graphs in Figure 5 provide participant responses to our post-workshop survey.

![Graphs showing workshop response to post-workshop survey.](image)

**Figure 5.** Workshop Response to Post-workshop Survey.

In analyzing the responses from those who would recommend this workshop to a colleague, we found that they cited the following aspects (shown in Figure 6) as contributing to their value of the workshop:
The one respondent who indicated that they would not recommend the workshop cited “content” as the reason. The other respondent who didn’t answer this question also cited “content” as the reason; although this particular respondent also indicated that they were “very likely” to use the learning suite materials in courses upon returning to their home institution.

Some verbatim comments from those who viewed the workshop favorably follow:

- “Prior to the workshop I thought it would cover more of the specifics of sustainability and how it relates to solid waste, water quality, etc. I was pleasantly surprised to find that the workshop focused on how to incorporate the skills to discuss and think about sustainability.” – Participant A

- “It was very educational and provides a more structured way to introduce these topics into courses.” – Participant B

- “It is refreshing to see this effort to move beyond fundamental knowledge, application, and integration in the education of engineers. This will greatly influence their ability to successfully implement sustainable solutions.” – Participant C

- “I found the ideas and practices presented in the workshop to reflect a lot of feedback I’ve received from faculty in diverse engineering courses who want to integrate things like teamwork, class discussions, and other interactive learning practices/techniques in the classroom. The workshop was effective in incorporating these practices into the framework of the workshop, thus demonstrating its effectiveness.” – Participant D

While all but one survey indicated positive comments in the open-response section of the survey. The one that was not positive was the following:

- “I feel it would have been more helpful to focus on how the text incorporates sustainability and suggestions for how we can implement these concepts into a
We note that 14 of the 20 participants actually signed up for the workshop ahead of time, while the other six attended because they were available. It is likely that the expectations of the content and the format of the workshop varied between participants. Some may have been expecting more traditional engineering content, such as life cycle analysis tools or design for environment approaches.

**Conclusions**

The development of learning suites followed Fink’s taxonomy of creating significant learning experience in terms of creating significant learning objectives, designing educative assessments and developing active learning activities and materials. The learning suites\(^b\) have been disseminated through a workshop format. The effectiveness of learning suites has also been tested through workshop participation. Workshop participants had an overall very positive response to the workshop, ideas and materials presented in the workshop. The major positive attributes of the workshop are utility of information, utility of activities, content and method. Based on verbatim comments from workshop participants, it was found that the learning suites we developed are very different from traditional learning materials and move beyond foundational knowledge and application. They guided the participants or learners on how to think about sustainability instead of just some sustainability related topics. The learning activities used in the workshop also demonstrate their effectiveness of engaging participants and enabling active learning.

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**Bibliography**


\(^b\) One can obtain copies of the learning suites by direct download from either of the following internet sites: [http://matesrv.cls.calpoly.edu/Ivanasup/Learning%20Suites/](http://matesrv.cls.calpoly.edu/Ivanasup/Learning%20Suites/), [http://bcs.wiley.com/he-bcs/Books?action=resource&bcsId=5086&itemId=0470165057&resourceId=17756](http://bcs.wiley.com/he-bcs/Books?action=resource&bcsId=5086&itemId=0470165057&resourceId=17756), or by visiting the Google group [http://groups.google.com/group/sustainability-learning](http://groups.google.com/group/sustainability-learning).


