Positioning Students to Understand Urban Sustainability Strategies through Vertical Integration: Years 1 through 3

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Mohamed grew up in Cairo, Egypt. Following college graduation in 2006 from American University in Cairo (AUC), he worked for several consultancy firms. He then joined a leading real estate corporation where he elevated to the post of a Deputy Project Manager for an office park project worth over hundred million USD. After completing his Masters of Engineering in Construction at the AUC, Mohamed could not bear the thought of leaving the School and so decided to change career gears from the industry to academia. Therefore, he pursued a Master of Science in Architecture degree focusing on design and energy conservation at the University of Arizona. Mohamed now is a second year Ph.D. student at Arizona State University. When not playing soccer, he spends his free time talking and reading about the sport.

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Positioning Students to Understand Urban Sustainability Strategies through Vertical Integration: Years one through three

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I. Abstract:

Commonly-adopted engineering pedagogy tends to be lecture-based, and places students in a passive and predominantly secondary role [1]. Research in the field of engineering education also highlights the ineffectiveness of such strategies and strongly advocates that faculty adopt advanced education strategies that actively engage learners. Citing medical education as an example, engineering education research suggests problem-based learning and vertical integration as two key strategies that will assist in facilitating the active engagement of learners.

This pedagogical implementation presents the progress from years one through three of an NSF TUES (Transforming Undergraduate Education in STEM) project that assesses the effectiveness of a vertically integrated problem-based learning (PBL) framework developed and implemented at "Arizona State University". The authors' framework integrates a lower-division construction management course, Construction Materials, Methods and Equipment (CON 252) and an upper-division civil engineering course, Urban Infrastructure Anatomy and Sustainable Development (UIA 507). The courses both address sustainability, and that provides a theme for vertical integration activities. The goal of introducing sustainability concepts is two-fold: to enhance undergraduate students' interest in and understanding of sustainability by engaging them in real-world sustainability projects; and to provide students with necessary knowledge for advancing a career in sustainability within Civil and Construction Engineering and Management (CCEM).

This pedagogy summarizes the progress and accomplishments of the project during years one through three by documenting the lessons learned each year, in addition to the evolution of the vertical integration PBL framework. The development and improvement of the vertical integration PBL framework depended on periodically collecting feedback from students and instructors to be able to analyze and amend the framework.

II. Introduction:

Sustainability is identified as a priority research area for the civil and construction engineering and management (CCEM) industries [2]. The tightening of human and environmental constraints is driving the engineering profession to think more rigorously about sustainability and the environment. A growing number of academics and professionals in CCEM infuse sustainability principles, including alternative energy, energy efficiency, and others, into their research. Sustainability is generally taught in upper-level classes, yet lower-level classes may include some supplemental sustainability course. Although undergraduate students may have an interest in sustainability, their exposure to it comes later in their educational curriculum [3].

Sustainability has been identified as a “wicked problem” [4, 6], unstructured and thus difficult to model, with multiple interconnected and integrated aspects that spans policy domains and levels of government. Research indicates PBL is an appropriate strategy for teaching students to engage in complex problem solving, and indeed may be one of the only effective methods for doing so [7, 8]. The vertically-integrated problem-based learning (PBL) framework developed in the course of this TUES project provides undergraduate students with both knowledge and tools needed to address urban sustainability issues in their future careers, whether in industry or academe. This framework is replicable and can thus be deployed across universities as part of the CCEM curriculum.

In this TUES project, the researchers develop a problem-based learning framework that (1) introduces sustainability earlier in the undergraduate curriculum, and (2) provides an opportunity for vertical integration across courses within CCEM curriculum. The goal of introducing sustainability concepts is two-fold: to enhance undergraduate students’ interest in and understanding of sustainability by engaging them in real-world sustainability projects; and to provide students with necessary knowledge for advancing a career in sustainability within CCEM.

The PBL framework is developed and implemented at "Arizona State University" between a lower-division construction management course, Construction Materials, Methods and Equipment (CON252) and an upper-division/graduate cross-disciplinary course between civil engineering course, sustainability, and planning, Urban Infrastructure Anatomy and Sustainable Development (CEE 507). CON252 focuses on the building design and construction process, ranging from excavation to material choice to various building systems. CEE 507 focuses on infrastructure systems from the technical and environmental perspectives and examines the interdependences between these infrastructures.

III. Motivation and Vision:

Introductory courses tend to be required for lower-division students and these courses act as prerequisites for upper-division courses that tend to be more discipline-specific and thus, may be more engaging for students. Introductory courses provide fundamental information and knowledge needed for upper-division courses. This framework continues throughout an academic course map, forming a linear advancement. Figure 1 shows this progression.

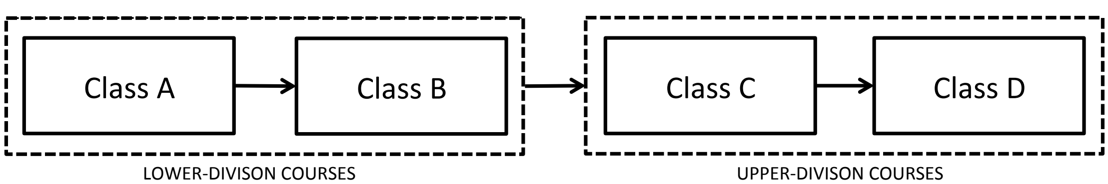

Figure 1: Linear Progression of Academic Courses

Class A provides knowledge needed for Class B, Class B provides knowledge needed for Class C, and so forth. Therefore, earlier classes such as Classes A and B are more focused on the fundamental concepts which then help students in their upper-division courses that are more conceptual and realistic (e.g., higher levels of Blooms). Though this progression is logical, it can result in lack of interest among students and therefore lack of retention. While there is a connection between more conceptual, upper-division courses and more fundamental, lower-division courses, this is hard to see in the lower-division course due to the lack of exposure to these upper-division courses in the earlier years. The authors have therefore aimed to create a framework that allows for a connection between upper and lower-division courses, as shown in the figure below.

Figure 2: Vertically Integrated PBL Framework Course Connection

This approach presents a framework that addresses the gap between upper and lower division courses through vertical integration and PBL. This framework leverages problem-based learning to support in-class student engagement and retention in science, technology, engineering and mathematics (STEM) fields. Vertical integration supports out-of-classroom engagement, which in turn serves student retention in engineering. The utilized "vehicle" for vertical integration is course projects, which lend themselves nicely to PBL. This framework will ultimately be transferable among different course types, educational levels, and universities. Specific aspects of this framework will be provided to successfully implement this vertically integrated PBL framework in another setting. This paper discusses and explores both the creation and implementation of this framework.

IV. Implementation of the Vertically Integrated PBL Framework

The vertical integration PBL framework was implemented three times at Arizona State University. These three implementations are the pilot approach, second implementation Spring 2015 and the third implementation Spring 2016. This section presents the results from years one through three of this program, highlighting the changes in approach and evaluation of the vertically-integrated PBL framework.

IV.i. The Pilot Approach

The vertically-integrated PBL framework was piloted in the Spring 2014 semester, and this implementation provided lessons learned that contributed to restructuring the framework. In the pilot implementation, students in the CON and CEE courses connected through one student group in CEE (Figure 3). Students from the lower-division course performed a quantity takeoff for this singular group, and did not interact with the entire CEE student body. Moreover, the integrative aspect was not stressed between the two courses as strongly as it should have been, as the idea of vertical integration did not resonate with student groups in either of the courses throughout the semester.

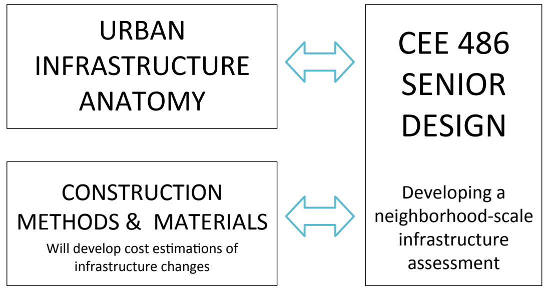

Figure 3: Vertical Integration Scheme for Pilot Implementation (Spring 2014)

IV.ii. Second Implementation: Spring 2015

Feedback from the pilot implementation suggested that students from both courses did not really feel any connection to students in the other course. Thus, the instructors adjusted their project assignments and encouraged more interactions between students, in addition, they included an evaluation process to enhance the implementation of the vertically-integrated PBL framework for the Spring 2015:

- Instructors added more opportunities for student interaction, including:
  - A formal kickoff meeting where student representatives from CON 252 met with all students from CEE 507.
  - A 'Request for Information' system that allowed for both professional and formal communication and collaboration between courses.
  - Encouraging CEE 507 students to attend CON 252 final project presentations.
- Instructors adjusted project assignments in both courses to better align with one another.
  - The final project for CON 252 focused on building a prototype for different building types (commercial office space, commercial retail space, single-family residential homes, multi-family residential homes, and other building types).
  - The class project for CEE 507 focuses on a more macro scale, and takes into account all building types focused on in CON 252.
  - UIA included four groups: Buildings, Transportation, Environment, and Social/ Institutions. Figure 4 shows how these groups integrate with the CON 252 groups.

	Commercial Retail Space	Commercial Office Space	Single-Family Residential	Multi-Family Residential	Other Building Types
New Construction	Team 1	Team 2	Team 3	Team 4	Team 5
	Team 6	Team 7	Team 8	Team 9	Team 10
Adaptive Reuse	Team 11	Team 12	Team 13	Team 14	Team 15
	Team 16	Team 17	Team 18	Team 19	Team 20

*Figure 4: Spring 2015 CON 252 Final Project Groups. The five teams highlighted in **blue** will work along side the Buildings group in CEE 507, the five teams highlighted in **red** will work alongside the Transportation group in CEE 507, the five teams highlighted in **green** will work alongside the Environment group in CEE 507, and the five teams highlighted in **orange** will work alongside the Social/Institutions group in CEE 507.*

The second implementation's overall project themes better promoted vertical integration between the two courses. Figure 5 demonstrates the vertical integration process.

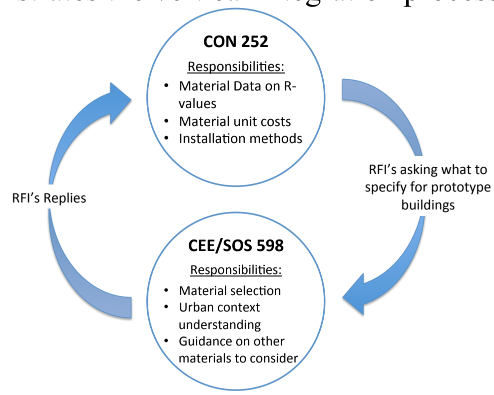

Figure 5: Vertical integration Scheme for Second Implementation (Spring 2015)

A more meaningful evaluator team was incorporated into the second implementation to better understand how CON 252 and CEE 507 students viewed the vertical integration. The evaluator team developed and executed pre- and post-surveys along with a mid-semester survey that assessed learning and collaboration throughout the semester. These surveys allowed for the assessment and improvement of the vertically-integrated PBL framework.

IV.iii. Third Implementation: Spring 2016

The authors conducted and assessed the third implementation of the vertically integrated problem-based learning (PBL) framework in the Spring 2016 semester. This iteration incorporated lessons learned in the previous implementations. The major variance between the third implementation and the previous two is embracing a collaborative product between the two courses, to make the integration more transparent. The Collaborative product, a report and presentation, requires that students meet and work together for their mutual and individual benefit. The framework develops students' technical and professional skills and encourages retention within "Arizona State University" CCEM programs.

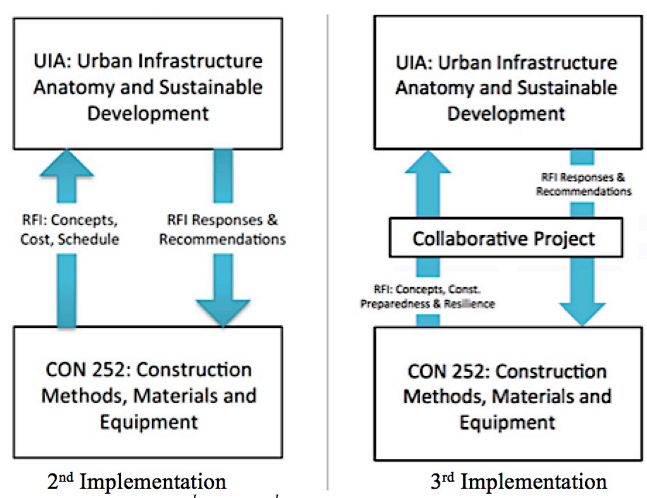

Figure 6: A major difference between the 2nd and 3rd schemes is that the second implementation of the vertical integration encouraged only RFIs as the mean of collaboration while the third scheme involved more collaboration by introducing a collaborative final project that required more face-to-face collaboration. (Spring 2016)

- The third implementation addresses the following deficiencies in the first two implementations:
  - *Aligned course projects* – In the first implementations, related lecture materials and project problems were the only academic and collaborative link between both classes. Thus, the third implementation requires sufficient collaboration to produce a collective product.
  - *Lack of Communication between the courses* – RFIs were proposed as the main communication medium between the two classes.
- The third implementation included all the merits of the previous implementations and added collaborative milestone deliverables:
  The Project Definition Rating Index (PDRI) – showed that front end planning efforts can significantly effect a project's success [5]. The PDRI – Small Infrastructure Projects effectively enables front-end project planning for small infrastructure projects. Students in CON 252 and UIA employed the PDRI – Small Infrastructure Projects to assess the level of completeness of their individual course projects.
  - *Evaluation of Resilience* – The students assess construction preparedness as an aspect of resilience in the face of the threat of flooding. CON 252 and UIA students collaborate to explore questions related to how quickly the construction industry could mobilize following a natural disaster. Students record their responses to these questions and produce sections of their respective project reports.
  - *Collaborative Deliverables* – These deliverables require students to meet and interact to prepare a single product that fits into both course's final project reports.

Instead of developing an informal peer mentoring relationship, the third framework intends to establish a formal relationship between the two groups of students. The upper-division students guide a team of lower-division students. The upper-division students also review lower-level sub-projects to provide constructive feedback to the lower-level students and to develop their own mentorship skills.

- RFIs should not be the only means of communication between the two classes, so the instructors required outside class meetings and site visits. Teams must document these meetings to demonstrate the face-to-face communication between both classes.
- Instructors added more opportunities and requirements for student interactions, by involving the CEE 507 students to serve as reviewers for CON 252 final project presentations.
- The team structuring and group formation between the two classes was amended to embrace a collaborative project. Figure 7 illustrates this new collaboration scheme.

		URBAN INFRASTRUCTURE ANATOMY & SUSTAINABLE DEVELOPMENT (UIA_CEE 507)				
		Group 1 Historical Extremes *(6-8 Members)*	*Group 2* Forecasting Flooding - Hydrological Model *(6-8 Members)*	*Group 3* Vulnerability *(6-8 Members)*	*Group 4* Adaptation: Fail Safe & Safe-to-Fail *(6-8 Members)*	*Group 5* Institutional *(6-8 Members)*
CONST. *METHODS, MATERIALS, & EQUIPMENT* (CON 252)	**Group A** *(5-6 Members including a Coordinator)*	*Member 1A*	*Member 2A*	*Member 3A*	*Member 4A*	*Member 5A*
	Group B *(5-6 Members including a Coordinator)*	*Member 1B*	*Member 2B*	*Member 3B*	*Member 4B*	*Member 5B*
	Group C *(5-6 Members including a Coordinator)*	*Member 1C*	*Member 2C*	*Member 3C*	*Member 4C*	*Member 5C*
	Group D *(5-6 Members including a Coordinator)*	*Member 1D*	*Member 2D*	*Member 3D*	*Member 4D*	*Member 5D*
	Group E *(5-6 Members including a Coordinator)*	*Member 1E*	*Member 2E*	*Member 3E*	*Member 4E*	*Member 5E*
	Group F *(5-6 Members including a Coordinator)*	*Member 1F*	*Member 2F*	*Member 3F*	*Member 4F*	*Member 5F*

Figure 7: Team structuring and collaboration between both classes, where a team member from each of the undergraduate groups will join one of the graduate groups.

As shown in the above matrix, each collaborative group consists of approximately 6-8 graduate students and 4-5 undergraduate students. These large teams collaborative to address specific elements of the UIA project with input from the CON 252 students. For example, one member of each of the undergraduate groups (A, B, C, D, E and F) will join Group # 3 of the graduate students. Group # 3 consists of 6-8 graduate students that focus on the vulnerability perspective of the UIA problem. Therefore, Group # 3 will host undergraduate members: 3A, 3B, 3C, 3D, 3E, 3F who focus on the UIA vulnerability perspective, and bring their construction knowledge to bear in those collaborations. Similarly, CON 252 student groups (A, B, C, D, E, and F) get exposed to the full scope of the UIA project, as each member of, e.g., Group A, leans a different aspect of the UIA project. This is akin to the construction industry, where a given member of the construction management team will address a specific scope of work, e.g., the mechanical system. Each of the undergraduate groups also has a coordinator who gathers information from all team members, and reports to the graduate coordinator.

V. Conclusion

Results suggest more collaborative projects support vertical integration, as these "force" students to integrate around a common topic. PBL provides a focal point for conversations throughout the semester, as students from each course visit the other course to introduce their unique course projects, and collaboratively develop solutions. Consistent communication between the two courses supports professional skill development in both upper- and lower-division student populations.

VI. Acknowledgments

This research is funded by grant DUE-1245205 from the National Science Foundation (NSF). This support is gratefully acknowledged. Any opinions, findings, conclusions, or recommendations expressed in this paper are those of the writers and do not necessarily reflect the views if the NSF.

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