A Cooperative Learning Approach to Designing, Analyzing, and Building a Structure as a Class

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Abstract — Students seem to have little trouble applying equations and using structural analysis methods but they often struggle with creating mathematical models, making appropriate assumptions, and approximating the response of structures, concepts that are not easily addressed with textbook problems. For the past three years students in my structural analysis course have worked cooperatively to design, analyze, and construct a structure for a non-profit organization in the community as a class. While active and project-based learning is becoming more popular in college classrooms and students often work in groups, the construction of a full-scale structure as a class seems a bit less common — both because it involves the construction of a full-scale structure and because the class must work together to build a single structure. A cooperative learning approach has been instrumental in the successful completion of the projects as well as in the engagement and learning of the students.

Keywords: cooperative learning, project-based learning, service learning, design, and structural analysis.

Goals and Objectives

Students seem to have little trouble applying equations and using structural analysis methods such as slope-deflection and matrix methods but they often struggle with creating mathematical models, making appropriate assumptions, and approximating the response of structures, concepts that are not easily addressed with textbook problems alone. This led me to explore project-based, authentic, and cooperative learning approaches. By having students design, analyze, and construct a structure they will:

- Create drawings and appropriate mathematical models of a structure,
- Approximate the response of a structure, and
- Compute actions and deformations in three-dimensional structures.

The students have been highly engaged in the projects, spending countless hours designing and building. While there are other approaches to meeting the above listed objectives, building a real structure seems to be the most engaging for the students. They found building models to be less engaging and reported learning more the years that the project involved building a real structure.

Background and Projects

For the past three years I have required students in my structural analysis course at the Thayer School of Engineering at Dartmouth College to work cooperatively to design, analyze, and construct a structure for a non-profit organization in the community. The projects in the course prior to 2009 involved design and analysis but not construction. Three years ago students created a loft structure for a local preschool, two years ago they built a worm-composting walkway for the Dartmouth Organic Farm, and this past year they designed and constructed a universally-accessible treehouse for a local community park. The class, with an average enrollment of 25, is an elective that is typically taken by juniors and seniors interested in mechanical or structural engineering (Dartmouth does not have separate departments). Solid Mechanics (i.e., Statics and Mechanics of Materials) is the only prerequisite for the course. Upon completing the course, students should be able to:

- Design, analyze, and construct a basic structural system,
- Create appropriate mathematical models for structural systems,
- Approximate the response of structures, and
- Compute actions and deformations in structures.

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Loft Structure (2009)

A loft structure for a local nursery school was the first real structure that the students designed, analyzed and built. A friend inspired me to pursue this project. The purpose of the loft was to provide additional space in the small school and provide a place for students to read and play. The nursery school is a nonprofit organization. They had some funding available for the project but not enough to purchase a loft structure or hire an engineer or contractor to build one. The students were able to design and build a structure that was approximately 8feet x 10feet with stairs to the upper level. The loft was ~4feet above the floor. The structure was built of wood – pine and cedar – available from the local lumber yard. Figure 1 shows the completed loft.

Worm Composting Walkway (2010)

In 2010, I had planned to go back to a project that involved creating models but not the building of a full-scale structure. The students, however, were very interested in building a full-scale structure so I contacted the coordinator of the Dartmouth Organic Farm. The class designed, analyzed and built a worm-composting walkway out of cedar, learning a lot about vermicomposting in addition to meeting the objectives of the course. Figure 2 shows the completed walkway; note that much of the structure of the walkway is buried underground and though not shown in the image there was an elevated portion of the walkway four feet above the ground as well.

Treehouse (2011)

This past year, the project was a treehouse for a local recreation area. Since the treehouse is open to the public, the Town of Hanover required that it be universally accessible. To avoid having an exceedingly long ramp to meet this criterion, we chose a sloping site. Handicap accessible ramps may only have a rise of 1 inch for every 1 foot of horizontal distance but by selecting a sloping site we only needed to rise by about 1foot from the adjacent bank to get 10 feet into the tree. The treehouse is small (~100ft²) thus no permit was required. It serves as a meeting space for local school groups who visit the area on science trips and to use the ropes course nearby. The treehouse was designed with slatted, removable walls and includes a loft space inside as well as storage benches. Figures 3 and 4 show the treehouse under construction and Figures 5 and 6 show the finished treehouse.
COOPERATIVE LEARNING

Overview

Cooperative learning is an instructional strategy through which small groups of students work toward a common goal to enhance their own learning as well as that of their group members [1]. Course assignments or activities are segmented into discrete tasks, with shared learning taking place. Simply putting students into groups to work together does not necessarily create a cooperative learning environment [2]. As a review, the key elements of cooperative learning are [3]:

1. **Positive Interdependence** – Projects should be structured such that all of the group members need to work together to achieve a shared or common goal. A well-designed project will be complex enough (for the allotted time) that completion requires contributions from all group members.

2. **Individual and Group Accountability** – While group members should be encouraged to work together, grading should include individual accountability. Ideally, some portion of the grade will be based on individual contributions or learning in addition to some portion assigned to the group as a whole. Peer assessment should be included in the grading structure. Objectives and roles should be clearly stated in the project statement.

3. **Promotive Interaction** – Students should be encouraged to work together, ideally face-to-face, and should be supported through instruction or resources. Time for interactions among group members should be a priority, both during and outside of class time.

4. **Social Skills** – In addition to content knowledge, students should be supported in their learning of social skills and encouraged to work effectively in a group. Social skills may be developed through discussion, readings, or team-building activities.

5. **Group Processing** – Groups should be encouraged to think not only about the content but about the process. Formative feedback that supports future group work should be encouraged. How is the group functioning? How could it function more effectively?

Cooperative learning is a student-centered instructional strategy that emphasizes cooperation among students as well as group work. Meta studies have shown that cooperative learning is superior to more teacher-centered, individual, and competitive learning approaches resulting in higher test scores, higher levels of critical thinking, higher levels of transfer, and improved ability to work in groups [4]. Students who learn in cooperative learning environments tend to be more actively engaged and motivated by the topic and have more frequent student-student as well as student-faculty interactions [5].

Implementation

So how did I implement a cooperative learning approach in my class? While each year the project was different, I developed an approach that I applied to each of the projects. I addressed each of the key elements of cooperative learning as follows:

1. **Positive Interdependence** – Each of the projects was complex and demanded a high level of engagement by all members of the class to accomplish. The common goal shared by the class was the design, analysis, and construction of a single structure. The class was sub-divided into groups of two to four to work on discrete portions of each structure – using the treehouse as an example one group focused on the ramp, another on the roof, another on the walls, and one on the railings. Within each group, students were assigned roles such as coordinator, estimator, or scheduler. The coordinator within each group was responsible for coordinating with other groups in the class to ensure that all of the pieces of the design worked together.

2. **Individual and Group Accountability** – For each phase of the project, students were graded both as a group and individually. Each project typically had three phases – a design phase, an analysis phase and a construction phase. For each phase I created a rubric outlining what I expected of each group member and how they would be assessed, with a portion of the grade being individually-based and a portion being group based. For example, in the design phase, each group member was required to create a unique design of the component assigned to their group (e.g., ramp or walls or roof) that was individually graded. Additionally, to the group submitted a “final” design and a design rationale for the group grade. During the analysis phase each group member was required to submit an analysis for a separate load case – of their component as well as the overall structure since one of the main objectives of the class was the analysis of a structural

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Forming groups

Forming effective groups involves many different aspects – composition, size, and selection. Research indicates that groups should be instructor-formed (rather than student-formed) so that students with different strengths and skills may be put into more diverse teams [2]. I formed teams in my class based on feedback that I collected from a survey. The survey included questions about their skills with computer programs and construction as well as their availability to work outside of class. The survey that I developed is adapted from one developed by Oakley, et.al. [2], with an additional question asking if there are other students in the class with whom they would like to work and with whom they would not like to work. Based on their feedback from the survey, I formed teams of 2-4 depending on the level of difficulty of the assigned task. I tried create teams with a diversity of backgrounds (including students both with construction and computer skills) and honored their requests for group mates where possible and appropriate. Groups were not always the same size – for example, for the treehouse only two people were on the bench crew, while 4 people were on the roof crew. Groups were formed early in the term for the design phase and reformed for the construction phase.

Logistics

Many of the logistics of the projects were handled by the Office of General Counsel and the Thayer School of Engineering at Dartmouth College. The Office of General Counsel gave advice on legal considerations, created indemnity agreements, and worked with the local building department. Funding for the projects came from the non-profit organizations themselves and outside donors with some support from the Thayer School of Engineering. Dartmouth College also helped with safety considerations. For example, the campus arborist set the initial bolts for the treehouse and installed safety lines into which the students could clip while working above ground.

PROJECT PHASES

Conceptual Design Phase

During the conceptual design phase, groups of three to four students were asked to conceptually design a structure (loft, walkway, or treehouse). I assigned the groups, honoring requests where possible and attempting to create balanced groups with a range of computer and construction skills. Early in the term the entire class visited the site and met with the client to discuss options for the design and requirements.

Groups were given class time to brainstorm ideas for their designs and to begin sketching ideas. Each student was required to create some rough sketches and ideas for the ideas on their own that they then brought to the group to discuss and modify. Each group was then required to create a single set of drawings (by hand or using computer-aided design software) of their proposed structure, a physical model of their proposed design, and a presentation. Conceptual designs were presented during the third week of the course to a review board as well as to the class. The review boards included engineers from the community and other professors from the department plus the client (the preschool teachers for the loft design, the head of the Organic Farm for the walkway, and the Director of Outdoor Programs for the treehouse). The review board and the class evaluated each of the different designs and discussed options for the final design. Students were highly engaged in the process and discussions and feedback were very
rich, with everyone providing input and working toward the design of a single structure; something that rarely happened when students presented individual designs or models. Discussions in class as well as written feedback formed the basis of the single final design. A rubric was used to grade the conceptual design phase and again included both individual (conceptual design sketches) and group (model and presentation) portions. Figures 7, 8, and 9 show examples of a computer-aided design drawing (using SolidWorks), a physical model, and a sketch – all created during the conceptual design phase of the treehouse project.

**Final Design and Analysis Phase**

After the conceptual design phase, groups were reorganized based on needs and interests. Each group was assigned to work on one aspect of the project (e.g., the stairs, platform, or railing for the loft) using a jigsaw approach. The jigsaw is a cooperative or collaborative learning approach through which each group member (or in this case each group) is assigned a separate task that contributes to the whole [6]. Using this approach enabled small groups of students to focus on separate aspect of the projects. Without using the jigsaw approach the class would not have been able to complete the projects during the 10-week term.

One person within each group was responsible for coordinating their design with other groups in the class. Coordination among groups was critical to the success of the project. Thus, in addition to having one coordinator within each group, I met regularly with each group to ensure that efforts were coordinated. Once a final design was fairly set, each student in the class was required to analyze their component as well as the overall system under a separate loading condition, again using a jigsaw-type approach [6].

At the end of the final design and analysis phase, each group presented their final design to the class and review board and submitted a set of calculations. The calculations were collated and submitted to the building department, if required. A rubric was again used to grade this portion of the project with a portion of the project graded individually (calculations for different loading conditions) and a portion graded as a group (presentation).

**Construction Phase**

After the final design and analysis phase, each group was responsible for constructing a certain component of the project; generally, the group that designed and analyzed a certain component was also put in charge of constructing that component. While one group was assigned to each component, groups helped each other when needed, and we used a wiki to sign up for work times and to keep track of who would be on-site at any given time.

Most the construction as possible took place at Dartmouth College, with only the final phases of construction occurring on-site to minimize transportation and supervision requirements. All students were certified through the woodshop on campus to use tools and numerous safety measures were put in place. For example, safety lines were installed for the treehouse project.

At the end of each project, a small celebration was held at the site with the client. For the loft project, the class interacted with the preschoolers at the end of the project as shown in Figure 2, answering lots of questions about the loft and engineering. Grading for the construction phase again used a rubric and was primarily based on the effort of
the group, with self and peer evaluations contributing to individual grades for this phase. Grading was based on completion of the project and time spent helping with construction.

**DISCUSSION**

All of the projects were successful in that the students completed all phases of the project, including construction, before the end of the term. And in all cases the client was happy with the constructed project. With respect to engagement, the students seemed highly engaged by the loft and treehouse projects and less engaged with the worm-composting walkway. This is evidenced somewhat by the number of hours they reported spending on course material outside of class at the end of the term. Prior to 2009, the average number of hours reportedly spent on course material outside of class time was between 10 and 15 hours/week. In 2009, 2010, and 2011, the average number of hours reportedly spent on course material outside of class time was 15.5, 14.6, and 19.1, respectively. Student spent numerous hours working on the treehouse, in particular, but never complained about the time they spent on it.

With respect to learning, the students reported learning more during the years that the project involved the building of an actual structure. Table 1 gives the student ratings at the end of the term when asked how the course facilitated their learning of the course objectives. Ratings are based on a Likert scale from 1 (not effective) to 5 (extremely effective). As shown in Table 1, the ratings were lowest in 2007, when the students were required to design a structure and build a model but not build an actual structure, and highest in 2010 when they were required to build a worm composting walkway. I actually, found these results somewhat surprising as I expected the ratings to be highest for the treehouse project, on which they seemed more engaged. A couple of possible reasons for this are that: 1) the class size in 2011 was quite a bit higher than in previous years at 35 and 2) the treehouse was a major undertaking requiring too much time to construct, in my opinion.

<table>
<thead>
<tr>
<th>Learning Objective</th>
<th>2007</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Please rate the effectiveness of this course in facilitating your ability to design, analyze, and construct a basic structural system.</td>
<td>3.50</td>
<td>3.88</td>
<td>4.57</td>
<td>4.45</td>
</tr>
<tr>
<td>Please rate the effectiveness of this course in facilitating your ability to create appropriate mathematical models for structural systems.</td>
<td>3.63</td>
<td>3.94</td>
<td>4.57</td>
<td>4.37</td>
</tr>
<tr>
<td>Please rate the effectiveness of this course in facilitating your ability to approximate the response of structures.</td>
<td>3.86</td>
<td>4.07</td>
<td>4.57</td>
<td>4.35</td>
</tr>
<tr>
<td>Please rate the effectiveness of this course in facilitating your ability to compute actions and deformations in structures.</td>
<td>3.75</td>
<td>3.94</td>
<td>4.63</td>
<td>4.40</td>
</tr>
</tbody>
</table>

When asked on the end of the term survey to comment on the course in general, 63% of the students in 2011 commented favorably about the project and 0% of the students commented negatively. In 2010, only 31% of the students commented on the project, all favorably. In 2009, 33% of the students commented on the project, with 11% of the comments being negative; the negative comments both mentioned that the project seemed somewhat disorganized. Since 2009 was the first year that I undertook the building of an actual structure, I take full responsibility for the disorganization of the project that year. In 2007, only 1 student (from a class of 12 students) commented on the project, stating that they “…learned virtually nothing from the design project.” A couple of the more informative comments from 2009, 2010, and 2011 are as follows:

- “The project, though a huge undertaking, was a great way to apply what we were learning in class to something real and worth investing in. It made the class memorable and well worth taking.”
- “The hands-on building project gave me a whole new understanding of applying engineering skills to the real world. It really motivated me to understand why we are learning certain topics in the classroom.”
• “The project allowed us to both use our knowledge from the course to design a structure and taught us a lot about problem solving … forcing us to find solutions with limited time and resources.”
• “I was not expecting the project to be good. I was happily surprised to find the project well organized and an effective project to teach me huge amounts about the practical aspects of building a structure.”

The main question to me is should I continue to have the students build actual structures? Or is it adequate to have them build models? While I need to more rigorously measure engagement and learning in the future, based on my experience and the self-reported evidence presented here, students are more engaged and learn more when forced to build the actual structure. This spring, the students will design and build affordable housing for Haiti.

**FUTURE WORK**

The January 2010 Earthquake in Haiti displaced over one million people, and now over two years later at least half a million people still reside in more than 850 camps [7]. There is an incredible amount of rebuilding & planning for permanent solutions that needs to occur in the areas of education, housing, jobs, and health care. I visited Haiti in September of 2011 as part of a team from Dartmouth College in conjunction with the $300 House Project. A blog post to the Harvard Business Review by Vijay Govindarajan (Earl C. Daum 1924 Professor of International Business at the Tuck School of Business at Dartmouth College) and Christian Sarkar (a marketing consultant) challenged designers to create a house for the poor for $300 as depicted schematically in Figure 10. The $300 House Challenge (http://www.300house.com) generated hundreds of design submissions and resulted in cash awards to the top sixteen entries. The top six competition winners, along with architects and engineers from Dartmouth and Haiti, recently attended a design workshop at Dartmouth College. I participated in the workshop and helped with designs for affordable housing. The next step is to continue designing, innovating, and testing different possible systems. I plan to have my students help with this effort; maybe we'll have our own $300 House Challenge within the course.

**REFERENCES**


**Vicki V. May**

Vicki V. May, Ph.D., P.E. is an Instructional Associate Professor of Engineering at Dartmouth College. Her research focuses on engineering education and K-12 outreach. Prior to relocating to the east coast, Professor May was an Associate Professor of Architectural Engineering at the California Polytechnic State University in San Luis Obispo.