A Multisensory Approach to Improving Student Efficacy in an Introductory Steel Design Course

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Abstract

Research on multisensory approaches to teaching demonstrate such methods have proven useful with students who lack well-developed visualization skills.[1, 2, 3] To improve the ability of students to visualize important lesson concepts in a 1st year steel design course, the author augmented the concept mapping structure used in the daily lesson plans to present material visually and aurally in the classroom with full-scale, 3D steel models of figures from the course textbook. Integration of these models into the lesson structure are shown to have had a positive impact on students' ability to visualize loads, load paths and failure limit states and thus conduct effective analysis and design. Class averages on graded problems involving lesson concepts related to the full-scale steel models are compared to averages from prior semesters to assess impact on student ability. Responses from course surveys are used to compare subjective parameters related to both ability and motivation.

Keywords: Multisensory, Teaching, Concept Map, Visualization, Efficacy

Introduction

During the first two semesters in which I taught our university's introductory structural steel design course, a required course for all civil engineering majors, I was fortunate to have small classes (Fall 2015: 19 students and Spring 2016: 15 students) which allowed me to get to know each of my students well in terms of their abilities and motivations. I was surprised though to find that a large percentage of my students had never been on an actual construction site or seen a building's structural steel frame up close during the erection phase of a project. The structural steel frame in a building serves as the building's skeleton which helps transfer loads placed on the building's components down to the structure's foundation. An understanding of how loads are collected by the building's components and flow through the steel framework is critical to the analysis and design of the individual steel members and connections. It became clear to me that I needed to augment the concept mapping techniques I already used to develop and present material on the white boards in the classroom with something that would replicate the advantages of an actual project site visit without the punitive time cost often associated with such forays. Using full-scale models of specific figures from the course textbook, especially ones which could be used in numerous general discussions to illustrate the engineering concepts and offered a good sampling of common structural members and connections found in a typical low-rise, steel framed building, struck me as something I should examine further to assess their potential for increasing student efficacy which I am defining as a student's ability to perform and motivation to learn.

Background & Theory

Research by Mayer and Gallini (1991) examined the impact text illustrations can have on student learning related to scientific concepts.[1] A few years later, Mayer (1997) sought to determine the conditions under which multimedia presentations improved the problem-solving transfer abilities of students by helping students connect visual and verbal cues.[6] Since my intent was to use the full-scale, 3D models to "illustrate" engineering concepts in order to "improve" my students' problem-solving abilities, their research seemed generally applicable to my situation.

Two prominent features of text illustrations, *system topology* and *component behavior*, proved most useful in helping students build mental models they could use to improve their current understanding and future performance. In a steel building frame, system topology refers to ensuring the illustration depicts the location of a steel member or structural component within the overall structural steel building framework. Component behavior refers to how loads flow through the member in question and the applicable limit or failure states and serviceability requirements that must be satisfied. 3D steel models offer the instructor the ability to highlight both prominent features. Concurrently, when combined with visual and aural teaching methods, the models seem like an effective means of connecting visual and verbal cues for students seeking to solve engineering problems.

Mayer and Gallini (1991) also referenced earlier research by Mayer in which he proposed four conditions that illustrations must meet to be effective in promoting understanding. In summary, (1) the text must present a cause-and-effect system to allow qualitative reasoning, (2) the text must facilitate the building of mental models, (3) the students involved must be inexperienced learners and (4) the tests used to assess student understanding and performance must be appropriate for the task considered.[1]

More recent research by Bui and McDaniel (2015) examined the impact of note-taking using outlines and illustrative diagram aids on student learning. In their studies, Bui and McDaniel, referencing Mayer and Gallini (1991), noted that although illustrative diagrams seemed to have a positive impact on a student's ability to construct effective mental models, their role in learning while students were also engaged in taking notes in a typical a lecture-style class as measured by performance on future tests was an area requiring further research.[4] This paper provides the details of an ongoing pilot study to help advance our understanding of the impact illustrative models, used as part of a multisensory teaching approach with visual, aural and tactile components, can have in improving a student's performance and motivation to learn

A Multisensory Teaching Approach: Visual, Aural & Tactile

The structural steel design course taught at Georgia Southern University is built around 30 lessons 75 minutes in length. Five lessons are dedicated to 90 minute long problem-solving labs and another two are set aside for exams. Graded assignments consist of a take-home review exam (50 points), five problem sets (250 points), two exams (300 points), two mind-mapping exercises conducted in conjunction with the exams (50 points) and a comprehensive Engineering Design Problem (EDP) (250 points) consisting of 10 separate submissions throughout the semester and a final presentation. I use attendance as a broad measure of class participation (100 points). I keep track of late arrivals and absences in order to compare poor performance with attendance should the need arise. I also ask each student to anonymously report how much time they spent since the end of the previous lesson ended preparing for the current lesson. Since I do not try to correlate names with the data provided on any given day, I feel comfortable using the time survey data as a measure of student interest and motivation. If the students like the course they will make an effort to be on time.

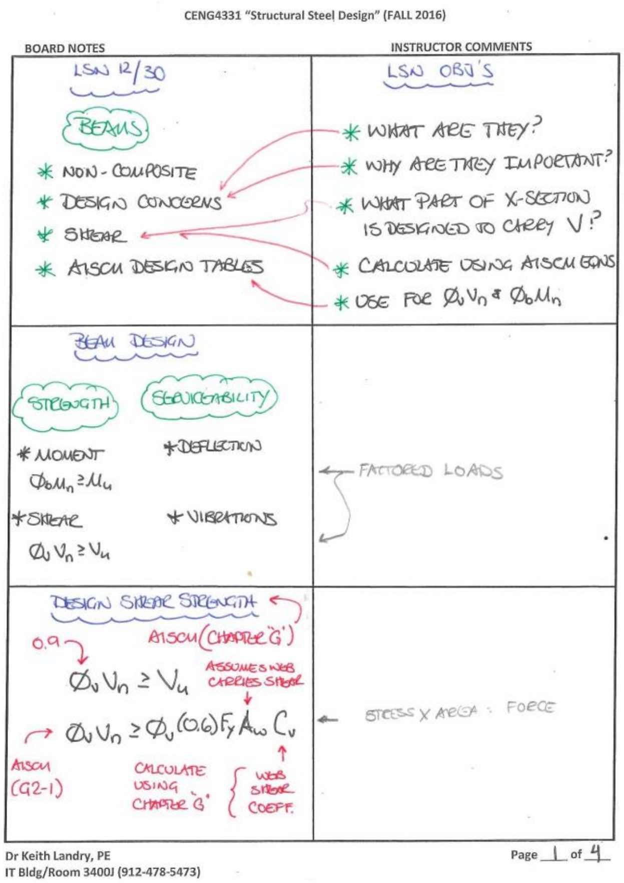

Figure 1: Example of Lesson Notes

I currently use concept mapping techniques to develop my lesson plans to meet planned objectives and present information visually, using a mix of specific colors on white boards in the classroom, and aurally, using both pre-planned and extemporaneous questions. Daugherty (2012) describe the traditional form of concept mapping as a collection of graphical node – arc representation of important concepts and their interrelationships.[5] The students are required to complete a concept-mapping exercise prior to each exam.

An example of the typical board notes I prepare in advance is shown in Figure #1. I preposition the lesson description and objectives on a white board in the classroom prior to the students' arrival. Most students come a few minutes early to copy the lesson objectives into their notes for the day. These organizational and visual methods have their foundation in the instructional techniques I first learned as a new instructor in the Civil & Mechanical Engineering Department at the United States Military Academy at West Point in 1995 and later refreshed after receiving my PhD in 2003. These same instructional techniques and lesson development methodologies were packaged by ASCE into their Excellence in Civil Engineering Education (ExCEED) program and have been taught each summer to engineering faculty around the country since 2000.[2]

In each course I teach, I take advantage of student feedback to help keep me on target as far as providing information to them in a manner that facilities their individual learning style and makes the subject material interesting. The mid- and end-of-course feedback surveys I conducted in the Fall 2015 and Spring 2016 semesters, the first two semesters during which I taught the steel design course, revealed that students responded exceptionally well to classroom organization and instruction during lectures but their performance on graded assignments indicated a sporadic, broad inability to visualize the concepts being presented. As a result, I commissioned full-scale models of nine specific figures from the course textbook.[3] The full-scale steel models replicating figures from the course textbook are shown in Figures #2-#7. I designed and commissioned a tenth model, also shown in Figure #7, to illustrate composite beam components along with multiple steel member and connection types.

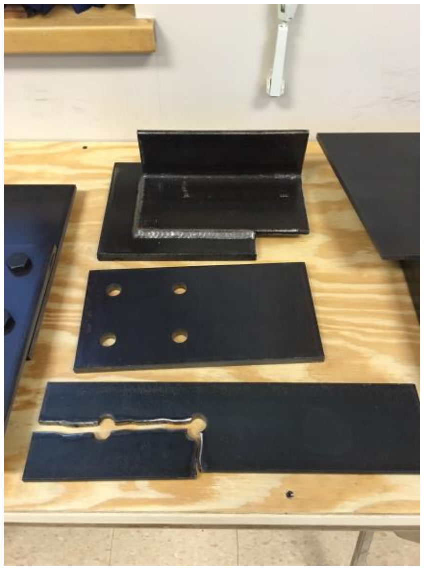

Figure 2: Block Shear & Bolted/Welded Connection Models

Figure 3: Bolted Angle-Plate and Plate-Plate Connection Models

Figure 4: Bolted Channel-Plate Model

Figure 5: WF Column and Baseplate Model

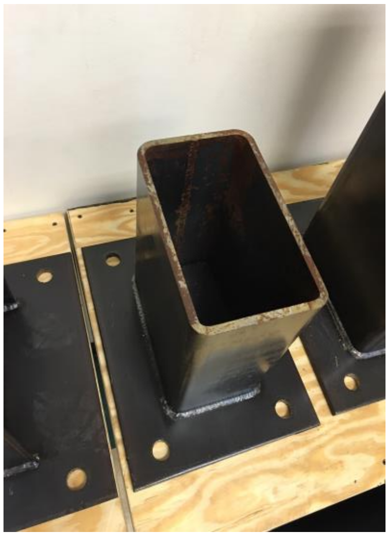

Figure 6: HSS Column and Baseplate Model

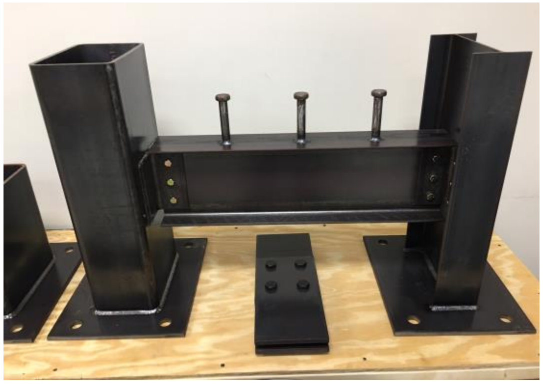

Figure 7: Composite Beam and Bolted Connection Model

The full-scale steel models of various members and connections were selected specifically for use during the appropriate lessons involving load paths as well as the analysis and design of tension members, compression members, non-composite beams, composite beams, beam-columns, bolted connections and welded connections. Table 1 correlates the figures selected from the course text to the course concepts being assessed. The models, applied to specific problems assigned as graded homework or used on exams, allowed me to bring their textbook to life in a manner of speaking. The full-scale models remain in the classroom and serve as daily classroom training aids. They are available to the students whenever the classroom is not in use during the school day.

Text Figure	Structural Steel Analysis & Design Concepts Assessed
4-11	Plate Steel with Bolt Holes: Bolt Bearing, Bolt Shear (Single), Block Shear, Edge distance, Tension Yielding, Tension Rupture
4-7	Welded Connection (Angle to Plate): Shear Lag Factor, Weld Length, Weld Group Geometry, Tension Yielding, Tension Rupture
4-1	Bolted Connection (Shear Plates): Bolt Bearing, Bolt Shear (Double), Block Shear, Edge distance, Tension Yielding, Tension Rupture
4-6	Bolted Connection (Angle to Plate) : Bolt Bearing, Bolt Shear (Single), Block Shear, Edge distance, Tension Yielding, Tension Rupture
4-9	Bolted Connection (Channel to Plate): Bolt Bearing, Bolt Shear (Double), Block Shear, Edge distance, Tension Yielding, Tension Rupture
4-24	Clevis and Turnbuckle: Tension Yielding, Clevis Design, Turnbuckle Design
8-56	Bolted Connection (HSS Column on Baseplate): Baseplate design
4-44 & 4-45	(Bolted & Welded Connections):
	- Shear Stud Design
	- Beam (WF) to Column (WF) (Bolted)(Bolted) Analysis & Design
	- Column (WF) to Baseplate Design (Welded)
	- Column (WF) Analysis & Design
	- Beam (WF) (Non-Composite Analysis & Design)
	- Beam (WF) (Composite Analysis & Design)
	- Beam (WF) to Column (HSS) (Welded)(Bolted) Analysis & Design

Table 1: Steel Model-Steel Design Course Concept Correlation

The research conducted by Bui and McDaniel (2015) found that student performance was greatly affected by the student's inherent structure building ability at the start of the experiment. Low-ability structure builders (i.e. weak ability at building effective mental models) showed the greatest improvement when provided with initial outlines for note-taking. They showed less improvement when provided with diagram aids and they took far less effective notes. High-ability structure builders received only marginal benefit from being provided outlines but performance improved when diagram aids were used. Thus, the use of full-scale models, combined with presentations of information using concept mapping techniques and an interactive questioning technique appears to offer a teaching approach with potentially positive impacts on students across the full spectrum of structure building ability.

Student Efficacy: Abilities & Motivation

To help me better focus the use of these steel models in class to highlight applicable lesson objectives provided to the students at the start of each lesson (e.g. Figure 1), I conducted a survey on the first day of class in the semester when I first had the steel models available for use (Fall 2016). This enabled me to subjectively assess the best mix of visual, aural and tactile approaches to use in class that term based on the learning preferences and structure building abilities of my students. The students were asked to identify how useful each of 20 different techniques or approaches were to helping them learn new concepts. The 22 students in the course were senior-level civil engineering majors. Table 2 contains the results of the survey along with the Likert scale definitions. Since a quarter of the course grade is invested in the EDP, which is completed in groups of 3-4 students, I used "Group Design Problems" as the cutoff to identify the preferred teaching techniques.

#	QUESTIONS (Likert Scale: 1-5)	AVG SCORE
1	PowerPoint slides	2.68
2	Concept maps or Mind maps	3.82
3	Problem solving labs	4.27
4	Exams (Multiple Choice Questions)	3.32
5	Exams (Problem Solving Questions)	3.95
6	Exams (Discussion Questions)	3.18
7	Graded homework	4.14
8	Course syllabus	3.41
9	Group design problems	3.68
10	Required use of mathematical software	2.82
11	Hands-on displays	4.09
12	Group work in class	3.64
13	Instructor-led Q&A discussions in class	3.91
14	Student in-class presentations	2.82
15	Student-led in-class problem solving	3.23
16	Instructor availability outside office hours	4.05
17	Instructor availibility during office hours	4.23
18	Use of Folio in class	2.82
19	Field Trips	3.77
20	Instructor enthusiasm	4.59

RATING SCALE
1 = Poor
2 = Low
3 = Moderate
4 = Good
5 = Excellent

#	Preferred Approaches	AVG SCORE
2	Concept maps or Mind maps	3.82
3	Problem solving labs	4.27
5	Exams (Problem Solving Questions)	3.95
7	Graded homework	4.14
9	Group design problems	3.68
11	Hands-on displays	4.09
13	Instructor-led Q&A discussions in class	3.91
16	Instructor availability outside office hours	4.05
17	Instructor availibility during office hours	4.23
19	Field Trips	3.77
20	Instructor enthusiasm	4.59

Table 2: Student Teaching Approach Preferences

Analysis of the initial survey results indicated that the steel models offered a potentially very effective means of augmenting my instructional approach, already based on visual and aural methods, with an illustrative, hands-on or tactile approach which students indicated they found helpful to their learning. 78% of the students scored Question #11 "Hands-on Displays" with a 4 or better. The survey also asked each student to assess their efficacy as defined by "ability to perform well" and "motivation to study and perform well" when it came to the structural steel design course. Table #3 below tabulates the results. On the first day of the course, just 55% of the students indicated they were highly motivated to perform well in a required course in their chosen major while just 22% believed they had the requisite skills to perform well in the course.

Q: Which quadrant do you feel you fall into right now based on your academic abilities as a civil engineer, as a result of your courses so far at Georgia Southern , and your motivation or willingness to study and perform well in this steel design course.

Table 3: Student Self-Assessment: "Efficacy"		**Motivation to Perform**		
		Low	**Moderate**	**High**
Ability to Perform	**High**	**0**	**3**	**2**
	Moderate	**1**	**6**	**9**
	Low	**0**	**0**	**1**

Efficacy Impact Data: Graded Homework – Attendance – Time Survey

To assess the impact of the steel models on the students' ability to better visualize load paths, identify applicable failure limit states and serviceability requirements, and perform required engineering analysis and design tasks, I compared the average class performance on homework and exam problems from each of three semesters: Fall 2015 (F2015), Spring 2016 (S2016) and Fall 2016 (F2016). Only the students in F16 were taught with the steel models integrated into the daily lessons. All comparisons were made at the same point in each semester (22 of 30 lessons completed)

Each semester during which I taught the steel design course, I used a consistent number of graded assignments: Problem Sets (5), Exams (2) and Engineering Design Problem (EDP) (1). Altogether, there are 35 graded problems students must complete. Although the problems assigned in any given graded assignment may change from semester to semester, the objectives being tested do not. At the point this paper was submitted in the S2016 semester, the students in the steel design course had completed four Problem Sets, one exam and ten of the twelve problems which make up the EDP. Across the three semesters in question, the students were graded on a total of 25 problems. Table 2 contains the average class scores for the 25 problems completed by a total of 56 students during the three semesters considered.

Problem ID	Problem Source	F2015	S2016	F2016
		19 Students	15 Students	22 Students
1	PS #1 Problem 1	80.79	83.33	80.00
2	PS #1 Problem 2	69.08	80.17	70.91
3	PS #1 Problem 3	60.13	85.50	81.82
4	PS #2 Problem 1	94.21	72.00	85.00
5	PS #2 Problem 2	89.74	59.78	61.59
6	PS #2 Problem 3	92.11	77.33	79.09
7	PS #3 Problem 1	80.39	77.11	88.64
8	PS #3 Problem 2	83.82	76.83	88.86
9	PS #4 Problem 1	68.15	95.33	88.18
10	PS #4 Problem 2	83.95	88.5	94.32
11	PS #4 Problem 3	62.89	84.00	92.27
12	Exam #1 Problem #1	64.56	86.40	69.8
13	Exam #1 Problem #2	87.53	87.50	89.9
14	Exam #1 Problem #3	82.63	89.70	84.7
15	Exam #1 Problem #4	75.47	97.3	68.7
16	EDP Problem #1	80.00	85.00	86.67
17	EDP Problem #2	86.32	87.00	89.89
18	EDP Problem #3	73.16	71.50	71.33
19	EDP Problem #4	69.47	68.00	70.67
20	EDP Problem #5	86.32	96.00	94.33
21	EDP Problem #6	81.40	86.00	94.00
22	EDP Problem #7	76.84	70.00	77.17
23	EDP Problem #8	86.84	71.00	93.00
24	EDP Problem #9	72.56	92.50	96.33
25	EDP Problem #10	75.09	92.00	92.00

Table 4: Problem Scores Comparison

Table #5 contains the student attendance data for each of the three semesters. Prior to the start of class, each student signs a roster showing they in fact were present at the start of class. When I start class, I highlight any missing students in order to track late arrivals and absences.

% of Students Present	F2015	S2016	F2016
@ Start of Class	85.41%	83.33%	88.84%
@ End of Class	95.93%	95.15%	97.73%

Table 5: Attendance Data Comparison

Concurrent with their self-reporting attendance by signing the class roster, each student anonymously self-reports how many minutes they spent preparing for that day's class since the previous lesson. This provides me with a broad measure of their individual effort spent "on task" outside the classroom. I do not track the time reported by sub-categories such as reading, problem sets or EDP problems. Table #6 contains the average minutes of prep time per student by semester.

	F2015	S2016	F2016
Average Minutes of Prep Time per Student per Lesson	43.1	80.0	100.6

Table 6: Time Survey Data Comparison

As an additional motivational incentive and to recognize outstanding performance, I award tabs modeled after the US Army's RANGER TAB in classes that I teach. To earn a tab, students must either score 100% on a Problem Set or above 90% on an Exam. The percentage of each class which earned at least one STEEL TAB is shown in Table 7.

	F2015	S2016	F2016
% of Students per Class Who Earned a Steel Tab	52.6%	66.7%	63.6%

Table 7: Steel Tabs Awarded

Discussion

Of the 22 students in the course this term, I had taught 11 the previous semester in our first-semester structural analysis course. I also taught three additional students in our highway design course the previous year. Thus 14 (64%) of the students had some familiarity with the visual and aural teaching approaches I used in the classroom.

Data in Table #3 indicates that, at the start of the S2016 semester, only 23% of the 22 students believed they had the abilities to perform well in the steel design course. Integration of the 3D full-scale, steel models into the existing multisensory teaching approach, containing visual and aural techniques, used in my introductory structural steel design course appears to have had a positive impact on their performance.

In Table #4, the cells colored in **GREEN** indicate student performance in the F2016 semester surpassed the student performance in both of the F2015 and S2016 terms. This outcome occurred in 52% of the graded problems. The cells colored in **AMBER** indicate student performance in the F2016 semester surpassed performance in one of the previous two semesters. This outcome occurred in 32% of the graded problems. Performance in the S2016 term failed to improve performance in the remaining 16% of the graded problems. In short, the augmented multisensory teaching approach had a positive impact on student performance in 84% of the graded problems evaluated.

As mentioned earlier, Table #3 shows that at the start of the S2016 semester, only 23% of the students believed they had the abilities necessary to perform well in the steel design course. Starting a course where most of the students did not believe they had the skills to succeed at a high level was a bit daunting. The fact that 55% of the students believed they had the motivation necessary to perform well was an indicator there was plenty of room to both teach and inspire them to exceed their self-assessments.

The time survey data in Table #6 indicates, that without increasing the graded workload, the average time spent preparing for each lesson self-reported by the students increased by 133% with respect to the F2015 term and 26% compared to the S2016 semester. The fact that this significant increase in prep time is not a function of an increase in graded requirements is indicative of a mix of increased self-confidence and interest in the course material.

Interestingly, a review of the scores for which students earned the Steel tabs described in Table #7 revealed that, in the F2015 and S2016 terms, no more than 30% of the tabs were earned based on problem set scores of 100%. Most were based on exam averages exceeding 90%. In the F2016 term, 11 of the 14 tabs earned (76%) came from scoring 100% on problem sets containing 2-4 problems. Despite the overall percentage of students earning tabs not increasing with respect to both previous semesters, the fact that students are now primarily earning tabs based on the more demanding criteria of scoring 100% on a Problem Set containing 2-4 problems seems to indicate a deeper understanding of the key engineering concepts in the course.

Conclusions

Research conducted using a multisensory teaching approach in an undergraduate structural steel design course appears to have improved the visualization abilities, problem transfer skills, and motivation of senior-level civil engineering majors. Augmentation of the concept mapping structure used in the daily lesson plans to present material visually and aurally in the classroom with full-scale, 3D steel models of figures from the course textbook improved student efficacy. Class averages on graded problems involving lesson concepts related to the full-scale steel models improved significantly compared to previous semesters when the models were not used. Increases in class attendance and time spent preparing for class are indicative of increased student motivation to both learn and perform well.

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