

Web-Based Interactive Steel Sculpture for the Google Generation

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Introduction

The Accreditation Board for Engineering and Technology, Inc. (ABET) requires that all civil engineering graduates must demonstrate that they can apply knowledge of four technical areas appropriate to civil engineering, and typically structural engineering is one of the technical areas. To satisfy this requirement, students take a design course in steel or reinforced concrete after they have completed the structural analysis course.

A typical introductory level steel design course includes the following topics: determination of load combinations with appropriate load factors; sizing of tension (axial), compression (columns), and flexural (beams and girders) members; and design of tension connections using mechanical fasteners and welds. In some cases, time permitting, an instructor may be able to cover additional topics such as shear-moment connection design. For a typical 15-weeks long semester course, about one to two weeks is devoted to connection design.

The lack of emphasis (about 10 % of the course) on connection design is by no means a reflection of its significance to the integrity of a structure. Instead, it is due to the time constraint and the common belief that connections are standardized details that should be left to the fabricators. However, the connections are the glue that holds a structure together. Historically, connection failures have contributed to many structural failures, for example, the Hartford Civic Center in 1977 [1], the Hyatt Regency Hotel in Kansas City in 1980 [2], and more recently, the I-35W bridge in Minneapolis [3]. Since the Hyatt Regency failure, many state licensing boards have made the connection design the responsibility of the engineer-of-record. Moreover, there are situations for which standard connection types would not be applicable, and engineers are required to design connections unique to a structure. A good connection design requires that the engineer to have a good understanding of mechanics and steel behavior and know the fabricator's limitations and experience. Often, what may appear to be an acceptable design (theoretically), in practice it may not

be feasible to fabricate in the shop or in the field. Hence, for these reasons, it is critically important that students, preparing for practice in structural engineering, develop a good understanding of connection design limitations and assembly. Typically, students have more difficulty understanding the assembly of connections than they do with the design of major components such as beams and columns. This is because of the three-dimensional nature and multiple possible connection assembly arrangements. This web-based tool was developed to overcome some of these obstacles.

It also is important to realize that before one develops a new learning tool, one should understand the end-user. Many of us (the faculty) belong to the baby boom generation. We were taught using blackboards, black and white textbooks with few illustrations, and were taught to understand orthographic views such as top, front, and side views. Today's students (the Google generation), on the other hand, are accustomed to whiteboards, multimedia presentations, multi-color, multi-illustration textbooks, and three-dimensional solid views. The Google generation has grown up with the internet, a comprehensive tool that provides a number of resources including detailed graphics, downloading capabilities for music and movies, and blogging. Cell phones and other electronic gadgets are also in much wider use [4]. Here are some additional facts – a survey of 7,705 college students in the U.S. [5] showed that

- 97% own a computer
- 97% have downloaded music and other media using peer-to-peer file sharing
- 94% own a cell phone
- 76% use instant messaging and social networking sites
- 75% of college students have a Facebook profile and most of them check it daily [6]
- 60% own some type of portable music and/or video device such as an iPod
- 49% regularly download music and other media using peer-to-peer file sharing
- 34% use websites as their primary source of news
- 28% author a blog and 44% read blogs
- 15% of IM users are logged on 24 hours a

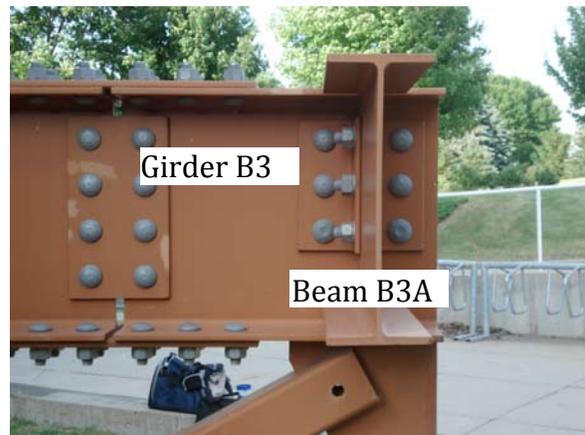
Abstract

In almost all the civil engineering programs in the United States, a student is required to take at least one design course in either steel or reinforced concrete. One of the topics covered in an introductory steel design course is the design of connections. Steel connections play important roles in the integrity of a structure, and many structural failures are attributed to connection failures. In recent years, in order to help students better understand the various connection types, many schools, including Minnesota State, have acquired steel sculptures. A steel sculpture is a physical system that shows forty eight types of connections found in standard construction practices. Unfortunately, because of its size and location (eight feet tall, weighs nearly 2500 pounds and usually erected outdoor), students do not have easy access to it. Moreover, today's students who belong to the Google generation are more comfortable with web-based learning tools. To provide an effective learning opportunity for the Google generation and to provide 24-7 hour access, we have created a web-based interactive version of our steel sculpture. The interactive sculpture shows the close up view of each connection with description, potential failure modes, sample calculations, and field examples. Moreover, to measure the effectiveness of this web-based tool, we conducted student surveys. In this paper, we describe in detail, how the interactive steel sculpture was developed, the results of the surveys, and how this tool could be used to enhance student's learning in a steel design class.

Keywords: steel connection designs, interactive steel sculpture, learning tool



View A. Double bolted-angle shear connection



View B. Double bolted-angle shear connection



View C. Double bolted-welded-angle shear connection, back of View B

Figure 1. Connecting two beams that are oriented normal to each other.

day/7 days a week

In the past, to accommodate the learners' backgrounds, we have developed physical models, moved from black boards to white boards, and changed to online deliveries (e.g., Blackboard, UCompass, Desire2Learn). We have transformed our classrooms to take advantage of new technologies. All these efforts are to narrow the generation gap and to better connect with our students and their learning styles.

During the past few decades, a great deal of attention also has been devoted to research dealing with how people learn [7-17]. One of the key characteristics on learning as discussed by Branford et al. [15] is that initial learning is necessary for transfer (apply previous knowledge in acquiring new knowledge). Although it may appear to be obvious, these studies showed the benefit of thorough understanding to transfer [7, 15]. In addition, motivation affects the amount of time people are willing to spend on a subject

to learn it. Learners are more motivated when they can see the usefulness of what they are learning [15]. Our understanding of how people learn in conjunction with the learners' background (the Google generation) are reasons for developing the tool discussed in this paper.

Steel Sculpture

Steel connections have always been designed as 2-dimensional elements (x-y and z-y planes) despite the fact that their load bearing behavior is 3-dimensional. Combining 2-D designs to yield a connection that supports a 3-D load bearing behavior is a concept usually very difficult for students to visualize. For example, when two beams (Girder B3 and Beam 3A) are oriented normal to each other as illustrated in Figure 1, we often use two angle sections to connect them. One of the angles will be in the front face of beam 3A and the other angle will be placed at the back face of beam 3A. The bolts

will then connect all three elements together as shown in Figure 1 – View B.

Figure 1 shows various views of the shear connections between a girder and two beams (Beams B3A and B3B connect to Girder B3). If we were shown only view A, we may conclude that the connection is a single-angle bolt connection. However, if we were given view B, then a structural engineer may think that the connection is a bolted double-angle. Further examination of the connection reveals that it is actually a two-double angle bolt and bolt-weld connection. View C shows the back side of view B. To show all the details of this connection on a blackboard (or whiteboard) would not be easy and would be difficult for most students to visualize.

In practice, the details would be shown as a series of two-dimensional drawings such as the construction sheets given in Appendix A. Appendix A is an example of a typical shop drawing that would be provided by the fabricator to the engineers for review and approval. Although the shop drawing depicts exactly how the connection is to be assembled, it is not easily understood by the students. A reason is that students typically have a one-semester exposure to computer-aided-drafting – a course that is usually taught by an instructor who has little to no experience in structural detailing. As for the above connection example, if students could not visualize the existence of another set of angles at the back face of Girder B3 (Figure 1-View B), it could lead to two common problems. First, students would not realize the significance and necessity of the second set of angles. Second, due to the visual absence of the angles, the students would forget to include it in the design calculations, and this could affect the safety and integrity of the structure. Furthermore, as often specified in a design the sculpture shows that the flange of Beams B3A and B3B must be coped to meet the top-of-steel-elevation requirement (top face of the beam and girder flanges must be at the same elevation so that the roof deck or floor deck can be placed on them). From the authors' experience, the coping detail is particularly difficult for students to comprehend from 2-D sketches.

Taking students to actual construction sites is one way to help them see how steel members are assembled. Although, this is a good approach, it is a major challenge to find construction projects that are nearby and underway during the term that the design course is taught. Often, liability issues also prevent the faculty to take students to construction sites. Because of these issues, many faculty members have



Figure 2. 8-ft tall steel connection sculpture at Minnesota State University

resorted to taking photographs of connection types from construction sites and then showed them to their students. Unfortunately, the photographs still do not show the true 3-dimensional nature of connections. In the summer of 1985, after seeing the inability of his students to visualize even simple connections, Professor Duane Ellifritt of the University of Florida designed a steel connection sculpture as a visual aid to teach his students about the many ways steel members could be connected. This thirteen feet tall sculpture has now been duplicated (duplications are only eight feet tall) and erected across 135 campuses in the United States. At Minnesota State, we acquired a duplicate of the sculpture (shown in Figure 2) in 2005. In addition to the physical sculpture, the American Institute of Steel Construction (AISC) also has prepared a teaching guide for the connections [18], which can be downloaded from the AISC website.

Interactive steel sculpture

The presence of the steel sculpture at Minnesota State (MSU) has certainly helped our students to see for themselves examples of connections that are taught in class and found in practice. The sculpture also has been used to teach students other considerations such as mechanical and electrical openings (in a structural element) that are required in an actual design that may not be covered in a class. We also use tours and photographs of actual exposed

steel structures as examples of practical application of the connections that are shown on the sculpture. The combination of the steel sculpture, tours, and photographs as teaching aids has greatly enhanced our students' understanding of the function of various connection types. While the eight-foot tall sculpture may fit in the lobby of some engineering buildings, the 2500 pounds load would require that the foundation be modified to support the sculpture load. Almost all the schools have chosen to display the sculpture outdoor, and in a cold region such as Minnesota, during winter months, it is not feasible to use the steel sculpture to supplement lectures.

While the steel sculpture serves a very useful purpose, the lack of 24-7 access has led us to develop the interactive sculpture. With the interactive sculpture, we can use graphics, hyperlink, and dynamic viewing to complement information about each connection. The interactive sculpture shows the close up view of each connection with descriptions, potential failure modes – that should be considered during the design process – sample calculations, and field examples. The interactive sculpture currently is a set of PowerPoint slides that can be accessed online at <http://cset.mnsu.edu/steelsculpture> and through the AISC's Web-Enhanced Teaching web site [19].

The development of the PowerPoint slides for the interactive sculpture was primarily the work of students who took the steel design course in 2006 and 2008. In 2006, students were asked to perform the following tasks as a class project.

1. Identify every connection in the sculpture in the order they are presented in the AISC Connections Teaching Toolkit [18].
2. Label the connections as identified from step 1 on the steel sculpture.
3. Take photograph of each connection.
4. Extract, from the Connections Teaching Toolkit, the potential failure modes of each connection.
5. Assemble the connection image and notes from step 4 into PowerPoint slides
6. Contact architectural and engineering firms to see what construction projects were underway at the time and take photographs of the actual structures with examples of connections as shown on the sculpture.

A student was chosen as the project manager to organize the PowerPoint slides and capture the close-up view of the connections, while other students provided information for the connections and field examples. Along with other

design projects, the students were given five weeks to work on this project. Because of the time constraint and the availability of actual construction projects within reasonable distance, students were not able to find field examples for every connection type demonstrated in the sculpture. Notwithstanding, this project exposed students to various types of steel connections and increased their interest in steel structures. It also helped them develop a keen eye for recognizing various connection types.

To further develop the interactive sculpture and to increase the database of field examples, in 2008, each group of two or three students in the steel design class was asked to perform the following additional tasks:

1. Select one connection type from the interactive PowerPoint file.
2. Identify all the limit states and meet with the instructor to confirm the limit states before performing any calculations.
3. Provide at least one field example for the connection type selected.
4. Perform detailed calculations for the connection field example.

Students also were encouraged to consult practicing engineers to obtain appropriate information for their projects. The work of the steel design class of spring 2008 contributed to nine sample connection calculations. Students selected all the necessary design parameters and then calculated the loading capacity of a connection based on the AISC design specification [20]. The interactive sculpture now offers over 100 interactive PowerPoint slides, with half of the connection types having at least one field example.

Navigating the Interactive Steel Sculpture

In this section, we will explain how to navigate the interactive sculpture and the corresponding PowerPoint slides. The user's guide can be accessed from the interactive sculpture directly. The first slide that a user sees when opening the file is the title slide. The user can either click the *start* or the *read me* button from the slide. The read me button links to the user's guide, a pdf file which gives a brief description on the navigation options. Once you click the *start* button, you will then see the disclaimer slide and the acknowledgement slide, then the north elevation of the sculpture (Figure 3).

From the north elevation slide, you can navigate to other elevation views by clicking

the *East Elevation*, *South Elevation*, or *West Elevation* button at the bottom of the slide. The numbers shown on the sculpture are the identification numbers of the connection types. All these numbers are hyperlinked to their corresponding connection details.

For example, you can access Connection 23 from the east elevation slide (Figure 4) by clicking on the number 23. This will link you to a close-up view of the connection and the limit states for which this connection should be designed (Figure 5). Note that at the bottom of this slide are the buttons for three possible links: *Back to East Elevation*, *Sample Calculations*, and *Field Example*. If you click the *Field Example* button, then you will be linked to at least one field application of the connection such as the one shown in Figure 6. If you click *Sample calculations* (Figure 5), you will be linked to a pdf file showing the calculations of the limit states of this connection. If you click the *Back to East Elevation* button (Figure 5), you will then return to the east elevation view (Figure 4), where you can select another connection or other elevation views. Note that at the bottom of Figure 6, there also are buttons for three possible links: *Back to East Elevation*, *Back to Connection*, and *more*. The *Back to East Elevation* button has the same function as the one shown in Figure 5. The *Back to Connection* button will return you to the connection description slide (Figure 5). The *more* button indicates that there are additional field examples. It is important to note here that all the connections depicted in the steel sculpture are only intended to show how steel elements are assembled. Moreover, the sample calculations are intended to show the equations used in analyzing the limit states of a connection. Therefore, the results of sample calculations reflect the capacity of the connection based on the member sections, number of bolts and bolt size, or weld length and weld size defined at the beginning of the calculations. None of the sample calculations represent the design of a connection for an actual project.

Measuring the Effectiveness of Interactive Sculpture

In order to assess the effectiveness of the interactive sculpture as a learning tool, we conducted a survey which required students to use the tool and answer a few questions. Twenty six students from the 2008 steel design class were asked to participate in the survey. At the time of the survey, the interactive sculpture was

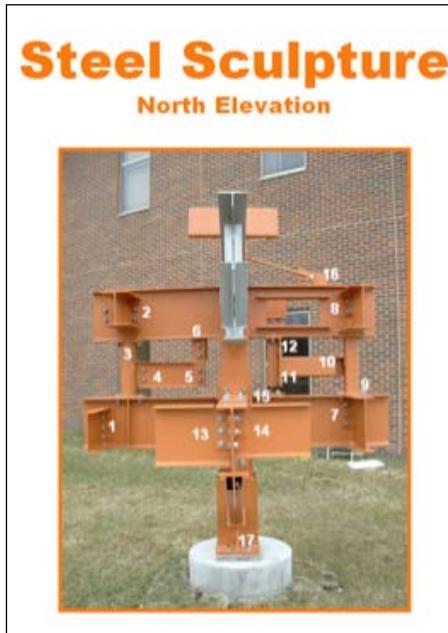


Figure 3. North Elevation view of steel connection sculpture.

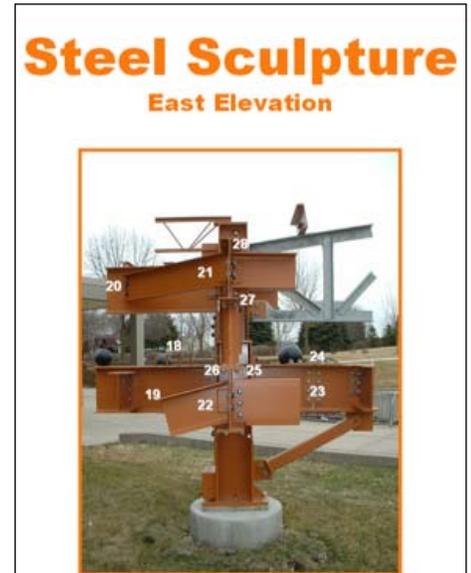


Figure 4. East Elevation view. Other views can be seen by clicking the respective elevation button at the bottom of the slide.

Girder B3 / Girder B3



Connection 23

- Plate Connection:
 - Web: Girder B3 is spliced at mid-span by an all-bolted moment splice

Limit States

- Block Shear Rupture
- Bolt Bearing
- Bolt Shear Rupture
- Flexural Rupture
- Flexural Yielding
- Shear Rupture
- Shear Yielding
- Tension Rupture
- Tension Yielding

Back to East Elevation
Sample Calculations
Field Example

Figure 5. Close-up view of connection 23 and the list of limit states this connection should be designed for.

available only through Desire2Learn (MSU supported online teaching software).

We recognize that conducting survey of the steel design class may not provide us with the best assessment information. However, as a

senior elective course, only one section of the course was offered. Thus, it was impossible to have a control section versus an experimental section (interactive users vs. non-interactive users) to compare the students' understanding on connection design. Moreover, there is no subsequent course in the students' undergraduate program that would require steel connection design specifically. So we could not measure the effectiveness of this tool in a follow-up class.

Background of the Students

With the physical steel sculpture being located outside our science and engineering building on the MSU campus, MSU, students were familiar with the sculpture and could see it up close while entering and leaving the building. They also had an opportunity to see the demonstration of the navigation of the interactive sculpture in class. In addition, students themselves contributed to some of the field example database and the sample calculations. These students were all taking the steel design course at the time. The design specifications used in the course were from the AISC Manual of Steel Construction [20]. We also used U.S. customary units.

Survey

The students were asked to spend about an hour on their own to navigate through the interactive sculpture and respond to the questions in the survey. In the survey, students were asked to

- rate the attributes related to this interactive tool such as quality of images (Q1);
- rate the effectiveness of the tool such as the learning concepts in enhancing your understanding of these concepts? (Q2);
- rate the overall usefulness of this tool? (Q3); and
- evaluate this education tool based on whether it provides a balance among connection types, field examples, sample calculations, and connectivity of structural members (Q5).

Summaries of the survey results for questions 1, 2, and 5 are shown in Figures 7, 8, and 9. As shown in these figures, students were generally satisfied with the interactive sculpture. All of the students, except for two with no responses, rated the overall usefulness of the tool as satisfactory or very satisfactory.

Furthermore, students were asked to list three beneficial components and three areas that need improvement. Examples of students' comments on beneficial components include:

Field examples – It is useful to “see the applica-

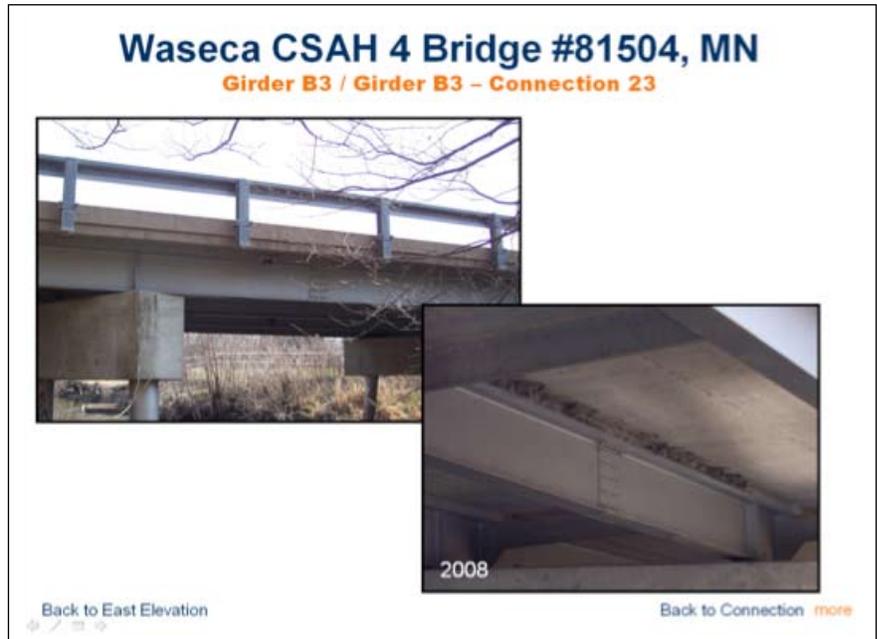


Figure 6. A field example of connection 23. A more button is shown at the lower right hand corner if more than one field example is available for the connection.

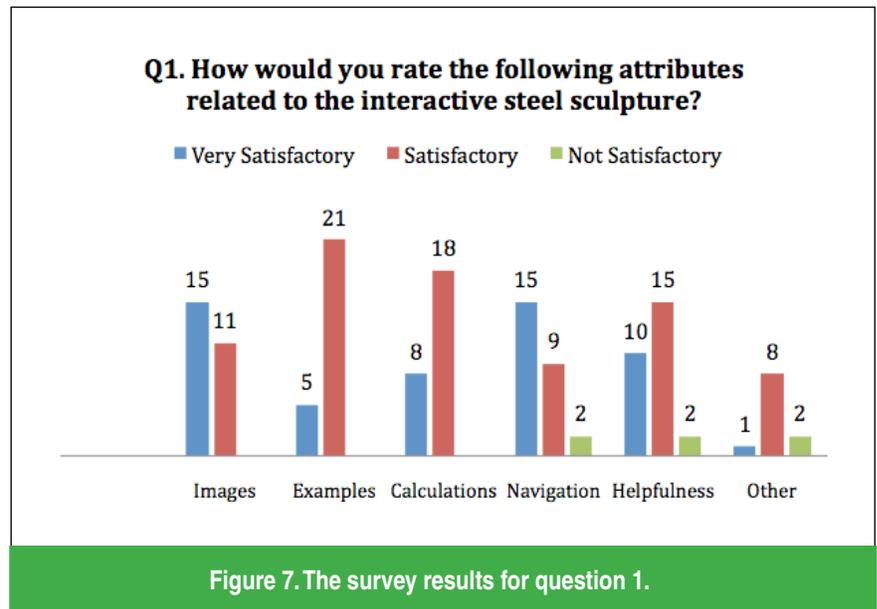


Figure 7. The survey results for question 1.

Q2. How would you rate the effectiveness of the tool in enhancing your understanding of the following concepts?

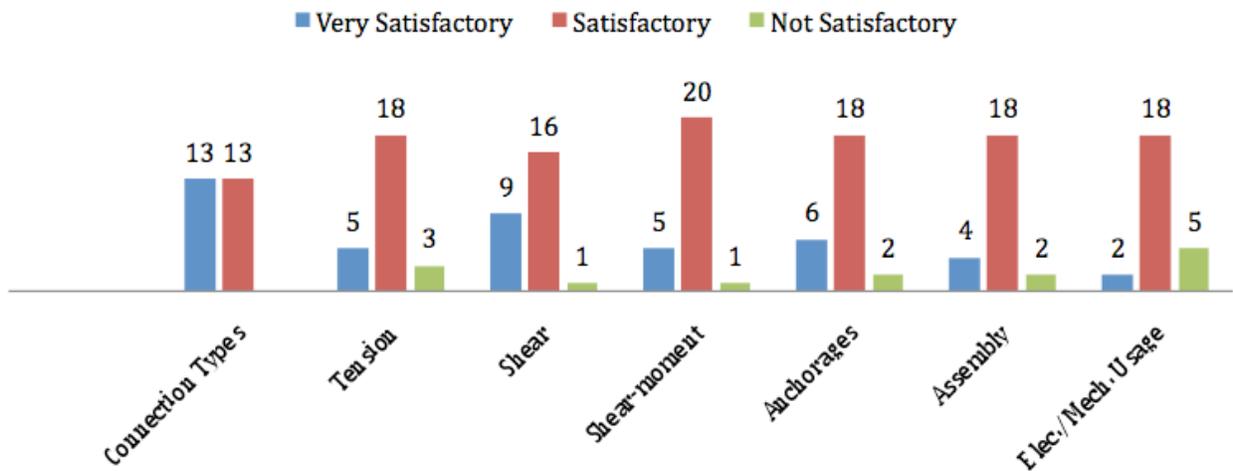


Figure 8. The survey results for question 2.

Q5. The interactive sculpture was created to provide a balanced educational tool:

- a. show different connection types
- b. field examples of connection types
- c. how connection calculations are performed
- d. how structural members are connected

From your experience, how would you evaluate this educational tool. Please check all that apply.

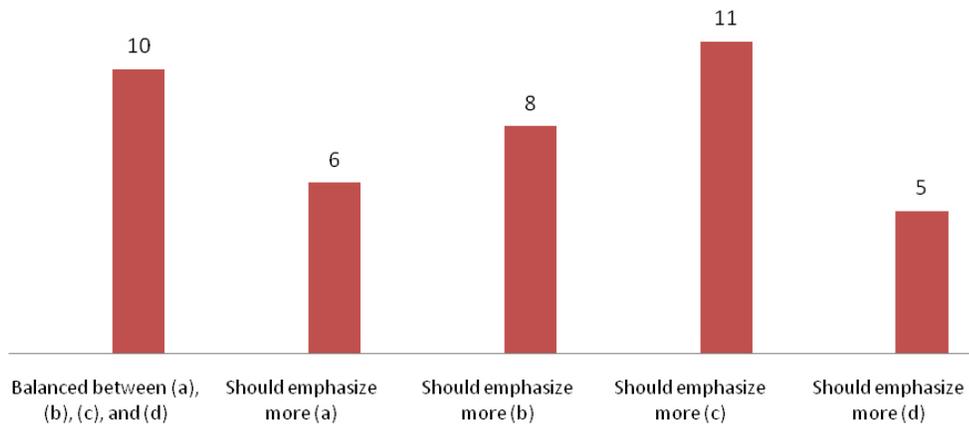


Figure 9. The survey results for question 5.

tions of various connections”

“Sample calculations are helpful”

It is useful to “see various types of connections”

“Nice interaction between connection, field examples, and sample calculations”

The students also suggested areas for improvement which included:

It is useful to see “360° view of the connec-

tions”

“Have sample calculations for more connections”

“Show how the connections fit into the entire structure instead of just a close-up view of the connections in the field”

“Link sample calculations from limit state in the connection description slide”

“File is too large, it takes too long to open from Desire2Learn”

To measure the usefulness of this tool in developing countries, we also asked students from Ghana, West Africa to provide assessment to our interactive sculpture. The interactive sculpture was loaded onto the personal computers in Ghana. The results of this survey and its comparison with our students' survey can be found in [21].

Concluding Remarks

The 8-ft high, 2500 pound, steel connection sculptures have been sprouting up in campuses around the country. The steel sculpture is designed to help civil engineering students visualize various ways steel members are assembled. The objective of the physical sculpture is to enhance the students' understanding of connection design concepts. It is necessary for the students to have a thorough understanding of these concepts in order for them to design the connections properly [7, 15]. To provide an effective learning tool for the Google generation and those students in developing countries who may not have access to a steel connection sculpture, the authors with the help of MSU students have created an online interactive version of a steel sculpture. The interactive sculpture shows the close up view of each connection with descriptions, potential failure modes, sample calculations, and field examples, and a balanced approach between theoretical concepts and practical examples that promotes transfer of learning [14]. To assess the usefulness of the interactive slides, the authors conducted surveys. Students were asked to explore the interactive sculpture and complete a questionnaire regarding the effectiveness of the steel sculpture as a learning tool. In general, responses were favorable and students' suggestions were constructive.

For the interactive steel sculpture to be complete and useful globally, we need to further develop the tool to include the following items:

- sample calculations should be based on multiple design specifications (other international design specifications) [21], not just based on AISC Manual of Steel Construction [20]
- field examples for every connection from projects around the globe
- sample calculations for every connection type including international ones
- provide a means for other educators around the world to submit field examples
- develop an efficient method on the internet to make the interactive sculpture available to students in developing countries with a limited internet bandwidth

To further improve the interactive sculpture, a 360° view of each connection is also necessary. Comments on practical application of each connection would be a great help to new graduates or engineers in training. For example, under what situation is one type of shear connection preferred over another. Based on the students' comments, the concept of interactive sculpture is good and the potential for its use as a learning tool is high.

The authors currently are in the process of creating a web site to make the interactive steel sculpture available to those students in developing countries with access to internet with narrow bandwidth. The authors also are currently seeking funding to expedite the development process.

Acknowledgment

The authors are grateful to the students (too many to name) in the 2006 and 2008 steel design classes for their significant contributions to this project. The authors also are grateful to the following entities for their contributions: Paulsen Architects for allowing us to use their projects for many of the field examples; Central Minnesota Fabricating, Inc. for donating the sculpture; and Central Sandblasting, Inc. for painting the sculpture; and MSU Office of Facility Management for providing the foundation of the sculpture.

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Appendix A Construction drawing of connection Beams 3A and 3B to Girder 3

