**Paper # 039 ENT 107**

# Enhancing Global Education: Making Steel Connection Sculpture Available Online to Students in Developing Countries

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## Abstract

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 civil engineering students better understand the various connection types and their importance, many schools in the United States including Minnesota State have acquired steel-connection-sculptures. A steel-connection-sculpture is a physical structure that shows forty eight types of connections found in standard construction practices. It weighs nearly 2500 pounds. The cost of materials, fabrication, and transportation to a campus site is incurred by the American Institute of Steel Constructions and their corporate members. Unfortunately, because of its high cost, this type of visual aid is not available to civil engineering students studying abroad, especially in developing countries. To provide the same learning opportunities for these students, we have created an online interactive version of our steel-connection-sculpture. The interactive sculpture shows the close up view of each connection with descriptions, potential failure modes, and field examples. It is available twenty-four hours a day to interested students. To measure the effectiveness of the interactive steel sculpture, we collaborated with Kwame Nkrumah University of Science and Technology in Ghana, West Africa and ask their civil engineering students to examine the helpfulness of this tool. In this paper, we describe in detail, how this interactive tool can be used to enhance student's learning in a steel design class and its effectiveness.

## Introduction

In almost all the civil engineering programs in the United States, a student would be required to take at least one structural design course. Steel and reinforced concrete design are the two primary courses that are offered by essentially every civil engineering program. Students who take a structural design course have already taken courses in statics, mechanics of materials, and structural analysis. Moreover, the steel design course is usually taken by a student during the third or fourth year of his/her 4-year program of study, and could be the student's first introduction to a formal design course. A traditional 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 as well as welds. In some cases, an instructor may be able to cover additional topics such as shear-moment connection design. For a typical 15-week long semester course, about one to two weeks would be devoted to tension connection design for both mechanical fasteners and welds.

The lack of emphasis (about 10 % of the course) in connection design within a course is by no means a reflection of the significance of connections to the integrity of a structure. Instead, it is due to the time constraint in a semester and the common belief in the past 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 placed the connection design responsibility on the engineer-of-record. Moreover, in a typical steel structure, there exists many occasions wherein standard connection types would not be applicable, and engineers are required to design "special" connections and specify all details. Hence, for these reasons, it is critically important that our students have a good fundamental understanding of connection design and assembly concepts.

Steel connections have always been designed as 2-dimensional elements despite the fact that their load bearing behavior is 3-dimensional. For students who are learning design for the first time and have no prior experience or knowledge of steel connection designs from summer internships, it would be difficult for them to visualize a three-dimensional connector. 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 would then conclude that the connection is a single-angle bolt connection. If we were given view B, then it is obvious to a structural engineer it is a double-angle bolt connection. 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 quite difficult for most students to comprehend and visualize its 3-D configuration. On the other hand, the true configuration of this shear connection can easily be observed from the steel sculpture or the interactive sculpture. In practice, the details would be shown as a series of two-dimensional drawings such as the construction sheets given in Appendix A. As for this particular connection, it would be difficult for students to visualize the existence of an angle at the back face of Beam 3A in Figure 1-View A and could lead to two common problems. First, students would not realize the significant and necessity of the second angle because of its absence in the diagram. Second, due to the visual absence of the second angle, the students would forget to include it in the design calculations, and this could affect the safety and integrity of a structure. Furthermore, the sculpture shows that the flange of Beams B3A and B3B must be coped to meet the top-of-steel-elevation (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) requirement often specified in the design. From the first author's experience, the coping detail is particularly difficult for students to comprehend from 2-D sketches.

An alternative to the steel sculpture is to take the students to actual construction sites to help them see for themselves various steel connections. Although this a good approach, finding appropriate construction projects in close proximity and during the term that the design course is taught is very challenging. Often, liability issues also prevent the faculty to take students to construction sites. Because of these issues, many faculty members have resorted to taking photographs of connection types from construction sites and showed them to their students. Unfortunately, the photographs still do not show the true 3-dimensional nature of connections.

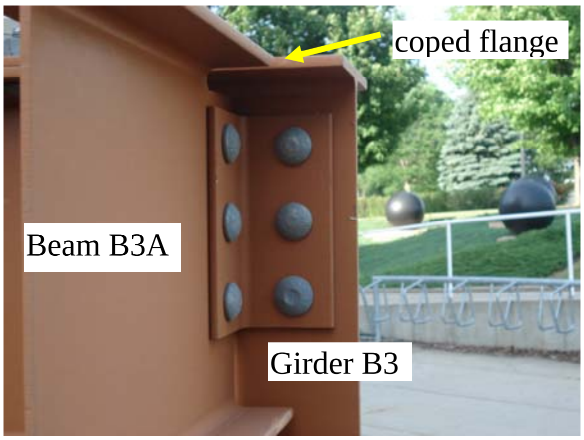



**Figure 1 – View A Double bolted-angle shear connection**

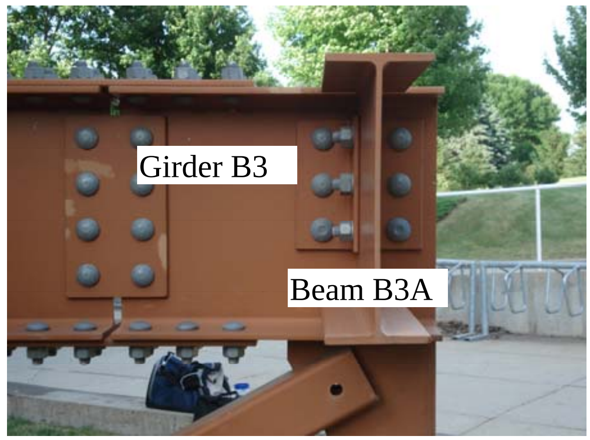



**Figure 1 – View B Double bolted-angle shear connection**

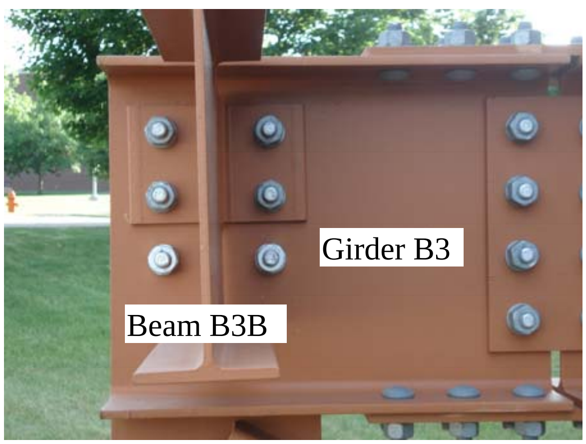



**Figure 1 – View C Double bolted-welded-angle shear connection, back of View B**

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 are connected to one another in typical construction practice. The cost of this project was underwritten by Steel Fabricators, Inc. This thirteen feet tall sculpture has now been duplicated (duplications are only eight feet tall) and sprouted over 135 campuses across the United States. At Minnesota State, we acquired a duplicate of the sculpture in 2005. The material and fabrication of our sculpture, shown in Figure 2, were donated by a member company of the American Institute of Steel Construction (AISC). In addition to the physical sculpture, AISC also prepared a teaching guide for the connections [4] which can be downloaded from the AISC website.

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

## Interactive steel sculpture

The presence of the steel sculpture at Minnesota State has certainly helped our students to see for themselves examples of connections that are taught in class and found in steel structures. The sculpture has also been used to teach students other considerations such as mechanical and electrical openings that are required in an actual design that may not be covered in a class. We also use tour and photographs of actual exposed steel structures as examples of practical application of the connections 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. Unfortunately, because of its high cost, the steel sculpture is not available to civil engineering students studying abroad, especially in developing countries. Moreover, using alternative materials such as wood to create a model of the steel sculpture is not economically feasible. The pieces of woods have to be machined, since most of the steel structures are composed of members with various cross-sectional shapes such as I, C, T, angle, or hollow rectangular or circular tubes. The manner in which members are welded together is yet another reason why a wooden model does not constitute a good alternative. In practice, the structural members are commonly made from hot-rolled steel that are welded together. As the result, the welded connections cannot be replicated using wooden models. Hence, in order to provide the same learning opportunities for students who do not have access to a steel sculpture, we decided to create an online interactive version of our steel-connection-sculpture to show the close up view of each connection with descriptions, potential failure modes, and field examples. We also decided that the interactive sculpture should be available twenty-four hours a day to interested students. Since the PowerPoint Slides offer great flexibility in creating an interactive multimedia, and as a starting point, the steel design class of spring 2006 was asked to produce PowerPoint Slides of the steel sculpture as a class project. The students were asked to do the following:

1. Identify every connection in the sculpture in the order they are presented in the AISC Connections Teaching Toolkit [4].
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 images of the actual structures with examples of connections as shown on the sculpture.

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 the field examples, in the spring 2008, each group of two or three students in the steel design class were asked to perform the following additional tasks:

1. Select one connection type from the interactive PowerPoint file. No duplication is allowed.
2. Some connections may require more calculations than others. Identify all the limit states and meet with the instructor to confirm the limit states before performing any calculations.
3. Provide a photograph of one field example for the connection type selected.
4. Perform detailed calculations for the connection field example.

Moreover, the students 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 additional sample connection calculations. The interactive sculpture now offers over

100 interactive PowerPoint slides, with half of the connection types having at least one field examples by either the students or the authors of this paper.

**Navigation of the Steel Sculpture**

In this section, we will explain how to navigate the interactive sculpture and the corresponding PowerPoint slides. 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 a pdf file which gives a brief description on the navigation of this interactive file. Once the user clicks the start button, he/she will see the north elevation of the sculpture (Figure 3).

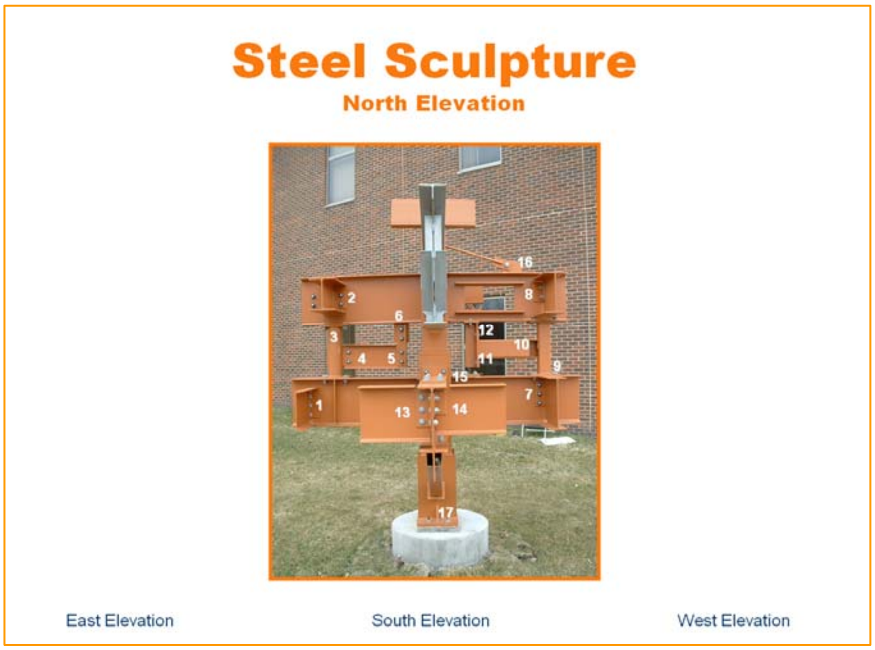



**Figure 3 North Elevation view of steel connection sculpture.**

From the north elevation slide, one 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. As an example, let us view the detail for connection 23.

Connection 23 is identified or hyperlinked from the east elevation slide. From the north elevation slide, we click the *East Elevation* button. From the east elevation slide (Figure 4), we will then click on the number *23*. This will link to a close-up view of the connection and the limiting states this connection should be designed for (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 the user clicks the *Field Example* button, then he/she will be linked to at least one field application of the connection such as the one shown in Figure 6. If we click *Sample calculations* in the connection description slide (Figure 5), we will be linked to a pdf file showing the analysis calculations of the limiting states of this connection. The first page of the sample calculations for connection 23 is shown in Figure 7. If we click the *Back to East Elevation* button in the connection description slide (Figure 5), we will return back to the east elevation view (Figure 4) to select other connections or other elevation views.


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


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

Note that at the bottom of Figure 6, there are also 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 us back to the connection description slide (Figure 5). The *more* button indicates that there are additional field examples. By clicking on the *more* button, we will be able to see the next field application for this connection type.

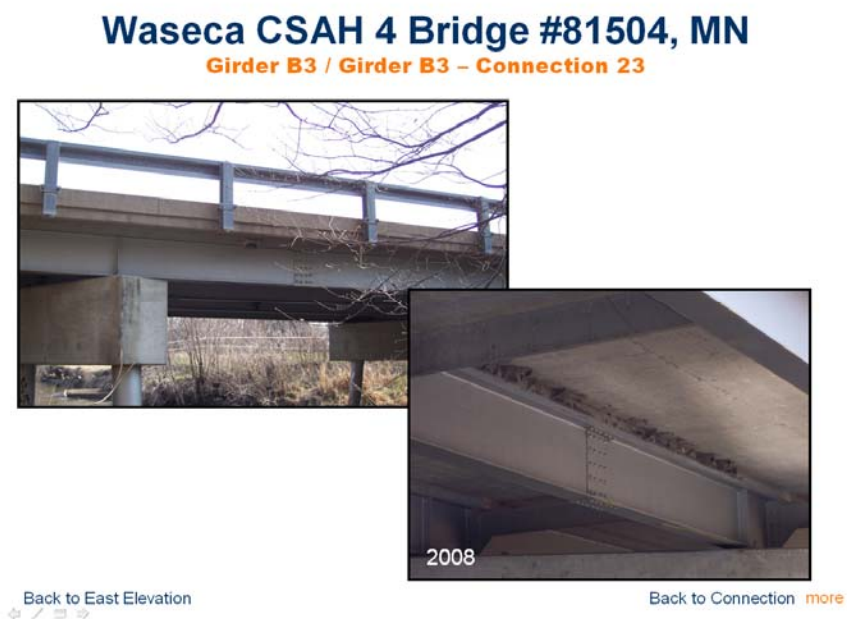
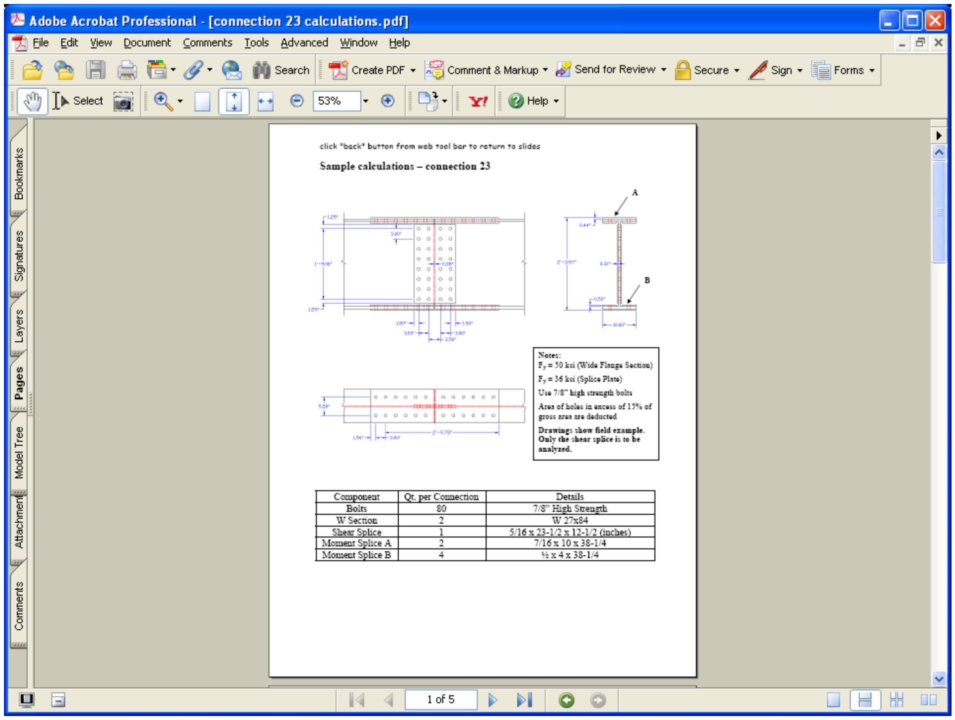



**Figure 6 A field example of connection 23. A more button is shown at the lower right hand corner if more than one field example is available for the connection.**

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 limiting 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 steel sculpture, as a learning tool, we conducted a survey which required the students to use the tool and answer a few questions. Groups of students from Minnesota State University (MSU) and Kwame Nkrumah University of Science and Technology (KNUST) in Ghana, West Africa participated in this assessment. A total of 54 students participated in the survey with 26 from MSU and 28 from KNUST.



Adobe Acrobat Professional - [connection 23 calculations.pdf]

click "back" button from web tool bar to return to slides

Sample calculations – connection 23

Notes:
$F_y$ = 50 ksi (Wide Flange Section)
$F_y$ = 36 ksi (Splice Plate)
Use 7/8" high strength bolts
Area of holes in excess of 15% of gross area are deducted
Drawings show field example. Only the shear splice is to be analyzed.

| Component | Qt. per Connection | Details |
|---|---|---|
| Bolts | 80 | 7/8" High Strength |
| W Section | 2 | W 27x84 |
| Shear Splice | 1 | 5/16 x 23-1/2 x 12-1/2 (inches) |
| Moment Splice A | 2 | 7/16 x 10 x 38-1/4 |
| Moment Splice B | 4 | ½ x 4 x 38-1/4 |

**Figure 7 The first page of the sample calculations for connection 23.**

The interactive sculpture was made available to the students via Desire2Learn (MSU supported online teaching software), and CD that was loaded into computers for the KNUST students. The MSU students had an opportunity to see the demonstration of the navigation of the interactive sculpture in class. The KNUST students, however, had to rely on the brief procedures that are described in the *read me* link on the first slide. Moreover, the steel design specifications in the United States are based on the AISC Construction of Steel Manual, currently in its 13$^{th}$ edition [5] and U.S. customary units are used. On the other hand, in Ghana, the design specifications are based on the British system and SI units are used. As we discuss later, the students' diverse design exposure between the two continents, North America and West Africa, influenced their responses to the 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, the students were asked to

- rate the attributes related to the interactive tools (question 1);
- rate the effectiveness of the tool in enhancing their understanding of the connection design concepts (question 2);
- rate the overall usefulness of the tool (question 3); and
- evaluate the various components of the tool (question 5).

Summary of the survey results for questions 1, 2, and 5 are given, respectively, in Tables 1 to 3. As can be seen from the tables, students were generally satisfied with the interactive steel connections slides. While students found the slides satisfactory, there is a distinct difference in the not satisfactory response between the MSU and KNUST students. In particular, the KNUST students found the navigation, calculations, and the design concept for electrical/ mechanical usage not satisfactory. All of the students, except for four with no responses, rated the overall usefulness of the tool as very satisfactory or satisfactory.

Table 1 Survey response for question 1.

| *How would you rate the following attributes related to this interactive tool?* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Attributes | MSU | | | KNUST | | | Total | | |
| | V.S. | S. | N.S. | V.S. | S. | N.S. | V.S. | S. | N.S. |
| Images | 15 | 11 | 0 | 21 | 7 | 0 | 36 | 18 | 0 |
| Examples | 5 | 21 | 0 | 9 | 18 | 1 | 14 | 39 | 1 |
| Calculations | 8 | 18 | 0 | 9 | 12 | 7 | 17 | 30 | 7 |
| Navigation | 15 | 9 | 2 | 6 | 14 | 8 | 21 | 23 | 10 |
| Helpfulness | 10 | 15 | 2 | 4 | 21 | 3 | 14 | 36 | 5 |
| Other | 1 | 8 | 2 | 2 | 13 | 1 | 3 | 21 | 3 |
| V.S. = very satisfactory; S. = satisfactory; N.S. = not satisfactory | | | | | | | | | |

Table 2 Survey response for question 2.

| *How would you rate the effectiveness of the tool in enhancing your understanding of these concepts?* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Concepts | MSU | | | KNUST | | | Total | | |
| | V.S. | S. | N.S. | V.S. | S. | N.S. | V.S. | S. | N.S. |
| Connect. types | 13 | 13 | 0 | 16 | 12 | 0 | 29 | 25 | 0 |
| Tension | 5 | 18 | 3 | 4 | 19 | 5 | 9 | 37 | 8 |
| Shear | 9 | 16 | 1 | 4 | 21 | 2 | 13 | 37 | 3 |
| Shear-moment | 5 | 20 | 1 | 6 | 20 | 1 | 11 | 40 | 2 |
| Anchorages | 6 | 18 | 2 | 5 | 19 | 3 | 11 | 37 | 5 |
| Assembly | 4 | 18 | 2 | 5 | 20 | 1 | 9 | 38 | 3 |
| Elec/mech usage | 2 | 18 | 5 | 4 | 10 | 10 | 6 | 28 | 15 |
| V.S. = very satisfactory; S. = satisfactory; N.S. = not satisfactory | | | | | | | | | |

Table 3 Survey response for question 5.

| *How would you evaluate this education tool?* | | | |
|---|---|---|---|
| Attributes | MSU | KNUST | Total |
| Balanced | 10 | 13 | 23 |
| More types | 6 | 1 | 7 |
| More examples | 8 | 5 | 13 |
| More calculations | 11 | 8 | 19 |
| More assembly | 5 | 7 | 12 |

One possible explanation for the significant variation between the two groups' responses to the question dealing with navigation is familiarity. The KNUST students were exposed to the idea of steel sculpture for the first time when they were asked to evaluate the interactive sculpture. On the other hand, MSU students had seen the actual steel sculpture on campus and were also shown the slides created by the 2006 steel design class.

The primary reason for the not satisfactory rating of the calculations from the KNUST students are the lack of familiarity with U.S. customary units and the different design specifications or code of practice in Ghana.

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

"field examples – see the applications of various connections"
"sample calculations are helpful"
"see various types of connections"
"nice interaction between connection, field examples, and sample calculations"
The students also suggested areas for improvement including:

"$360^{o}$ view of the connections"
"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"

The KNUST students offered additional suggestions that are slightly different from the MSU students because of the design specifications, system of units, and their limited exposure to the steel sculpture. Their suggestions include:

"use SI in sample calculations"
"need more explanation on sample calculations"
"more local field examples"

Although the KNUST students appeared to be more critical of the quality of the interactive sculpture, the comments are valid and constructive. As previously discussed, KNUST students had never heard of a steel sculpture until their instructor requested the assessment of the interactive sculpture. The lack of familiarity with U.S. design specifications and the field examples (all from Minnesota) contributed to their suggestions for improvement.

## Concluding Remarks

The 8-ft high, 2500 pounds, steel connection sculptures have been sprouting up in campus in the United States. The steel sculpture is designed to help civil engineering students visualize various ways the steel members are assembled together. To provide the same learning opportunities for students who do 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, and field examples. To assess the usefulness of the interactive slides, the authors conducted surveys in steel design classes at MSU and KNUST in Ghana. Both groups of 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, the response from Minnesota and Ghanaian students were all favorable. Their suggestions were also very constructive. For the interactive steel sculpture to be complete and useful globally, we need to include the following:

- sample calculations should be based on multiple design specifications (other international design specifications), not just based on AISC Manual of Steel Construction [5]
- field examples for every connection from projects around the globe
- sample calculations for every connection type including international ones
- provide a mean for others 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 $360^o$ 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 from Minnesota and Ghana, the concept of interactive sculpture is good and the potential for it to be a great learning tool and reference tool is very 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 are also currently seeking resources to expedite the development process.

## Acknowledgement

The authors are grateful to Dr. Mark Adom-Asamoah, Senior Lecturer at the Department of Civil Engineering, KNUST, Kumasi, Ghana, for his assistance in conducting the survey. We also appreciate the KNUST students' efforts in assessing the interactive sculpture. We are also indebted to our MSU students for their assistance in developing and assessing the interactive sculpture.

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## Biographical Information

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