

Virtual Steel Connection Sculpture – Student Learning Assessment

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Abstract

A Virtual Steel Connection Sculpture was developed through a grant from the National Science Foundation. The Virtual Sculpture is an interactive tool that shows students and anyone interested in connections how steel members are connected. This tool is created to complement students' steel design courses. The features of this educational tool, which shows how steel members are connected to build a structure such as a building or a bridge, are discussed in detail in three other papers. Learning assessment was a crucial component during the development process, as it was important to measure the effectiveness of this tool in enhancing student's understanding of steel connection types. The focus of this paper is on the student learning assessment of this 3-D interactive educational tool.

Introduction

Through a grant from the National Science Foundation (NSF), we have created a 3-D interactive Virtual Steel Sculpture^[1]. This tool offers not only an effective learning platform but also provides a 24-7 access to students and educators in the United States and abroad. The Virtual Sculpture is based on the physical model that is located on the campus of Minnesota State University, Mankato. The model has 48 connection types and additional features that are not included in the original steel sculpture at the University of Florida.

While the Virtual Sculpture is enjoyable to use, interesting, and full of technical information beyond connection assembly, the goal of the Virtual Sculpture is to enhance the students' knowledge in connection design. Since most introductory level steel design courses do not have the time to cover connection design extensively, the Virtual Sculpture would serve either as a supplement to the course or a complete self-taught learning module. To provide incentive for student learning and to help the instructors assess student learning, a set of quizzes was developed and available for download along with the Virtual Sculpture files on our web site at: <http://faculty.mnsu.edu/saeedmoaveni/>.

This article is one of the four papers on the Virtual Sculpture. The first paper discusses in great detail the

development of the 3D model^[1]. The second paper is on the finite element modeling of the connections^[2]. The third paper explains the calculations of the limit states of each connection^[3]. In the following sections, we will describe the assessment process used during the development of the Virtual Sculpture. The assessment process also formed the basis for the online quizzes which were developed later. The objective of each quiz is also described in detail in this paper so that the instructors can use the quizzes for quick assessment or more in-depth probing of students' learning.

Assessment process

Assessment is central to the development of any learning process or tool. We sought assistance from the Northwestern University Searle Center for Advancing Teaching and Learning (Searle Center) to develop the assessment activities and survey forms. A Searle Center researcher with assistance from a civil engineering graduate assistant used an experimental study designed to assess the effectiveness of using the Virtual Steel Sculpture on students' understanding of simple connections.

Sixteen undergraduate students and one M.S. student from an introductory level structural steel design course

were randomized to one of two homework conditions (Figure 1). In the "sculpture condition" (S group), students were given instructions on how to access the Virtual Steel Sculpture. At the time of assessment, the animation portion of the Sculpture was complete and the S group could view any of the 48 connections at will. However, it is important to note that at that time, only the sample calculations for one shear connection type was available. In the "textbook condition" (T group), students were given a chapter from a textbook that is commonly used in steel design courses. Both groups were asked to complete the same homework assignment of studying a connection design not covered in class. The teams consisted of two students except for one team with 3 students. The aim of the homework assignment was to have the students engage with the Virtual Steel Sculpture or read the assigned material. Students did not receive a grade for the assignment; however, they did receive credit for completing the assignment. All students completed the homework assignment.

Two construction activities were developed to assess students' understanding of simple shear connection assembly. Both activities required students to form connections with small cardboard structures that were labelled

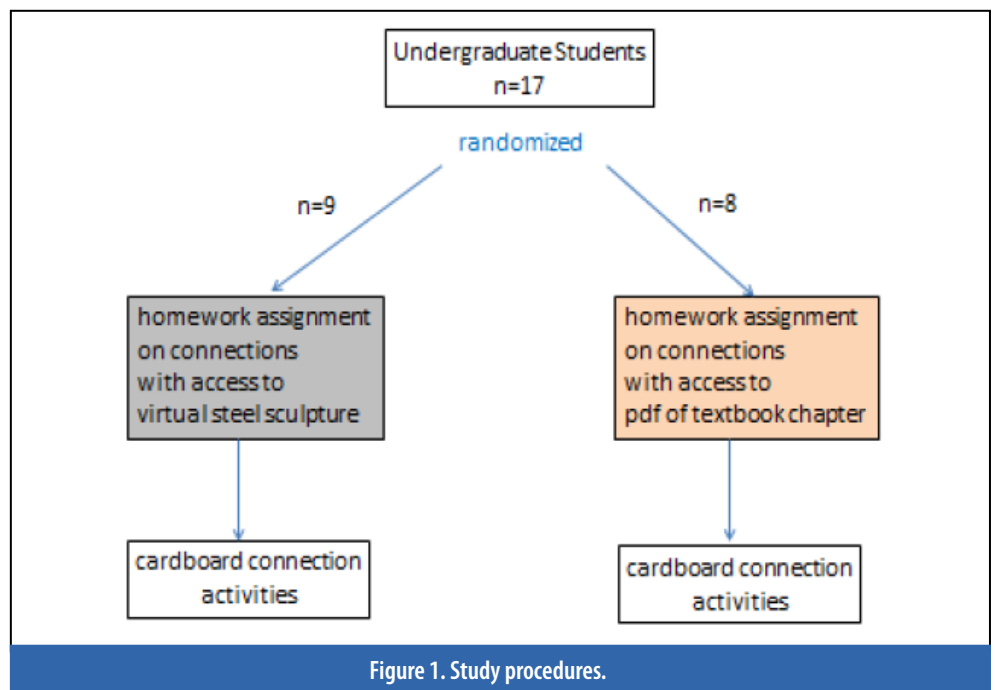


Figure 1. Study procedures.

Activity 1

Materials: Two (2) I-shape cardboard beam members labeled as Girder (tallest and biggest) and Beam (shorter and lighter than Girder).

Instructions:

1. Consider the Girder is a major component of a bridge and the beam is a brace member to prevent lateral torsion buckling of the Girder, show how you would attach the Beam to the Girder?
2. Why did you decide to attach the beam to the Girder the way you did?
3. Anything you should consider in this attachment?
-The response should not include bolt size, bolt strength, weld size, weld strength, etc.
- Since this is a simple shear connection between two flexural members, response should be on the connecting element where an angle or bend-plate is commonly used. The Virtual Sculpture has more examples of using different connecting element shapes such as plate, WT.
- If angle is used, both legs of the angle could be bolted or welded to the beam webs; or one leg is welded and the other leg is bolted to the beam webs.
-If it is the latter, does it matter which leg should be welded?

Figure 2. Materials and instructions given to students for assessment activity 1.

Activity 2

Materials: Two (2) I-shape cardboard beam members labeled as Girder (tallest and biggest) and Beam (shorter and lighter than Girder).

1. Consider the Girder is a major component of a building and the Beam is one of the floor beams (this requires the top of both the Girder and Beam be at the same level), show how you would attach the Beam to the Girder?
2. Anything you should consider in this attachment?
- The response of coping should be said in part 1.
- The response for this part should be the same as the response in part 3 of Activity 1.

Figure 3. Materials and instructions given to students for assessment activity 2.

as beams and girders. The instructions for the activities are presented in Figures 2 and 3. Students completed the activities in pairs (with one team of 3 students). For each activity, they were given a cardboard beam and a cardboard girder. They were then given a scenario and asked to show how they would attach the beam to the girder. In the first activity, they were asked to provide their reasoning for why they made the connection in the particular way that they did. In both activities, they were asked about anything else they would consider in the connection, for example, bolts should be used in both ends of the connecting elements such as an angle. Activities described in Figures 2 and 3 were given to the Searle Center researcher and the graduate assistant only. The italic font in the figures denotes the notes from the course instructor to the Searle Center researcher and graduate assistant.

During the assessment session, held during class time, the Searle Center researcher read a standard set of instructions for each task to the students. The graduate assistant who helped with designing the task answered any questions that the students had about the instructions for doing the task, but did not give them feedback on their progress or the correctness of their responses. One of the PI of the project was present as an observer. The other PI who is also the course instructor was not present to minimize any anxiety the students may have had. Only one team of students was present at a time during the assessment session.

Once students were satisfied with their connections, the assemblies were photographed by the graduate as-

sistant. The graduate assistant assessed the students' connections, classified them as correct or incorrect and made notes on the nature of any errors that were made. Both the researcher and the graduate assistant were completely blind to the condition, "sculpture" (S group) or "textbook" (T group).

Assessment results

Activity 1 – Each team of students was given a beam and a girder that were made of cardboard. The team was asked to use the beam to provide support to the lateral-torsional buckling of the girder. The task required the students to connect the beam to the girder. Since the beam is not required to support the deck or slab such as bridge deck, the proper assembly would be as shown in Figure 4, where neither beam flange would be in contact with either girder flange. Bolts, welds, or both can be used for the connection. All 8 teams performed activity 1 correctly so a detailed discussion of each group will not be presented. Figure 5 shows the girder-beam assembly demonstrated by one group of students.

Activity 2 – Each team of students was given the same beam and girder as in activity 1 (a new beam was provided when a team destroyed the beam used in activity

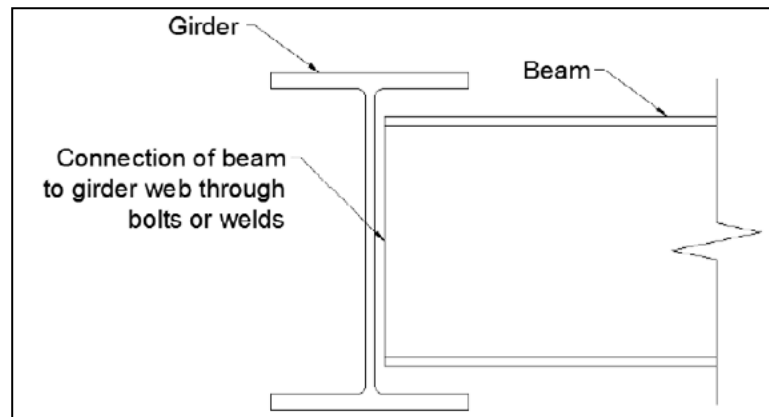


Figure 4. Typical solution for Activity 1.



Figure 5. Typical correct student solution to Activity 1.

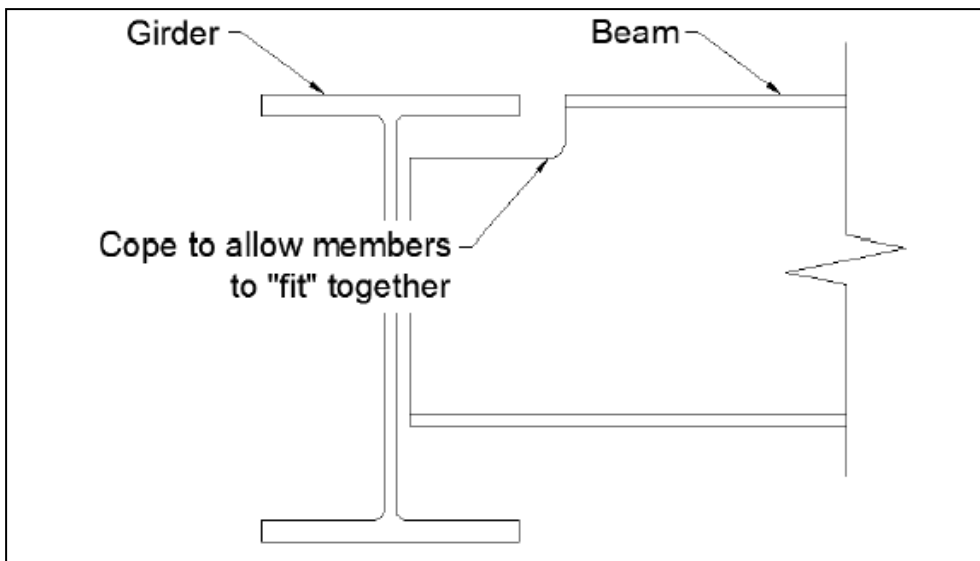


Figure 6. Typical solution for Activity 2.

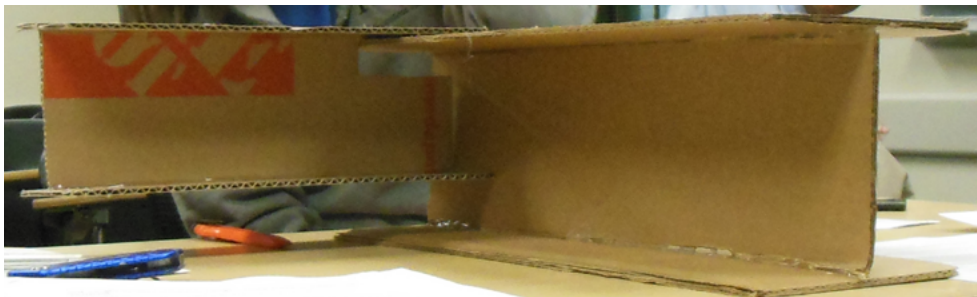


Figure 7. Team S2's solution (correct with minor errors)



Figure 8. Team S4's solution (correct)



Figure 9. Team S6's solution (correct)

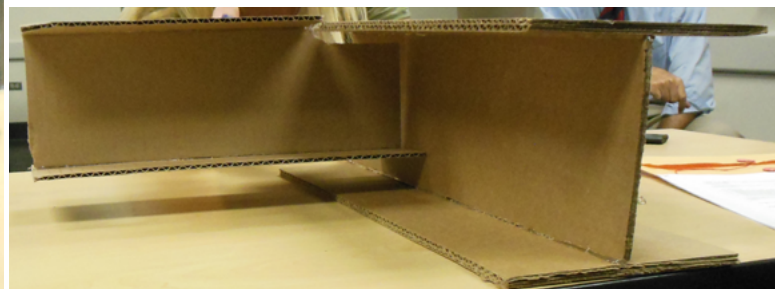


Figure 10. Team S8's solution (correct)

1). The team was asked to assemble the beam and girder so that they form a floor support system where the assembly is used to support a leveled floor. Since the beams are often used to carry the floor loads and then transfer the loads to the girder, the top flange of the beam must be leveled with the top flange of the girder. In order for both the top flanges of the beam and the girder be leveled, the top flange of the beam and part of the beam web have to be coped. Figure 6 shows the proper connection between the beam and the girder.

Unlike activity 1, there were marked differences in student performance in the 2 different conditions. The majority of students who were randomized to the sculpture condition (S group) connected the beam and girder correctly; 3 teams performed the task correctly and one team was partially correct with a minor error. In contrast, the majority of students randomized to the textbook condition (T group) connected the beam and girder incorrectly; one team performed correctly with a minor error and 3 were incorrect. Each team's performance is discussed in detail below and photographs of the connections are included. The teams are numbered by the order in which they performed the activity.

Analysis of connections made by "sculpture condition" S group – Team S2 got the theory part correct. The students recognized part of the beam needed to be removed in order to make a flush connection with the girder (coping). However, they did not quite get the coping correct (Figure 7). Their coping did not yield a leveled surface between the beam and the girder. Both the flange and part of the web of the beam should be removed, instead of a slot in the web causing the beam flange to land on top of the girder flange. Teams S4, S6, and S8 correctly connected the beam to the girder as shown in Figures 8-10.



Figure 11. Team T1's solution (incorrect)



Figure 12a. Team T3's first solution (incorrect)



Figure 12b. Team T3's second solution (correct with minor error)



Figure 13. Team T5's solution (technically correct and practically challenged)



Figure 14a. Team T7's first approach (incorrect, similar to Team T1's approach)



Figure 14b. Team T7's second approach (incorrect, similar to Team T3's second approach)



Figure 14c. Team T7's third approach (incorrect, similar to Activity 1)

Analysis of connections made by “textbook condition” T group – Team T1 incorrectly placed the beam on top of the girder (Figure 11). This is symptomatic of confusion between how engineers idealize structures for analysis and how they are actually constructed. Since girders are meant to support beams, in an idealized load-path sketches (for analysis) engineers place the beam loads on top of the girder. However in practice the loads are transferred from the beam to the girder through the connection at the webs of the beam and girder. This is necessary to achieve leveled floor.

First, team T3 made the same mistake as team T1 (Figure 12a). After realizing that the two members

needed to be flushed, they attempted to move the beam so that the beam flange is leveled with the girder flange but did not cope the beam (Figure 12b). This would require an extended shear tab and significant moment could be developed in the connection.

Team T5's approach in connecting the beam to the girder was technically correct when they coped the top flange of the beam (Figure 13) without coping part of the beam web. Practically, this connection would be difficult to achieve. Moreover, the flange thickness of the beam is usually not the same as the flange thickness of the girder. Hence, team T5's approach would ensure some form of interference between the beam web and top girder flange.

Team T7 tried three different approaches and failed to identify the need to cope in each approach. The first approach was similar to team T1's (Figure 14a); the second was similar to team T3's second attempt (beam and girder flange were flushed but the beam was too far away from girder; Figure 14b), and the final approach was similar to the solution of activity 1 except the beam was inserted into the clear space of the girder just below the top flange (Figure 14c).

Other considerations

At the end of each activity, each team was asked if the team had anything to consider regarding the attachment. This question was not intended to lead the students to a specific answer. The expectation was that the students would discuss the connecting element, bolts

and/or welds being used. Table 1 summarizes each team's response.

Regardless of the students' preparation for the hands-on assessment activities, there were multiple identical responses.

- The students chose to use either single or double angles as the connecting element.
- There was little to no difference in the way they would attach the angle(s) to the webs of the beam and girder between Activities 1 and 2.
- When using both bolts and weld to attach the beam to the girder via the angle(s), almost all the teams except one would weld a leg of the angle to the web of the girder and bolt the other leg to the beam web. In practice, this is usually the other way around.
- The students were conscious of the limit states of the connection.
- The S group teams unanimously suggested that the coped beam section should be checked for strength limit state.

Comments – The student performance from the two groups on the cardboard connection activities suggested that interacting with the Virtual Steel Sculpture may enhance students' understanding of connections. While there was no difference between the groups on the first activity there was a substantial difference in performance on the second activity, with the majority of teams who had interacted with the Sculpture forming correct connections and the majority of teams who had interacted with the textbook forming incorrect connections.

From the responses on the open-ended questions at the end of each activity, one can draw the following rationales for their responses.

1. Single and double angles were used in example problems when block shear and fracture were analyzed for axial members.
2. The students were more familiar with the bolted connection as the weld connection was not discussed in the course.
3. In the steel design course, limit states analysis was discussed extensively for tension, flexural, and compression members as well as axial connection designs.
4. The visualization of a coped beam, with reduction in cross sectional area, led students to address the strength of the coped beam. This is a valuable observation from the students.

Development of online quizzes

The activities using the cardboard beams clearly illustrated the students' understanding of beam-girder connection under two different situations. Activity 1 is usually associated with bridge design and activity 2 is more common in building design. While these cardboard beam activities are good, significant amount of work and time are required from the instructors. If the class size is

Team	Activity 1	Activity 2
"Sculpture Condition" (S Group)	S2 <ul style="list-style-type: none"> • connecting element: angle • weld at beam or girder and bolt at the other member • multiple members: weld angles to all the members 	<ul style="list-style-type: none"> • check limit states on the coped beam section • same connection detail as Activity 1 • bigger angle may help
	S4 <ul style="list-style-type: none"> • connecting element: double angles • not sure if bolts or welds should be used • coped beam to fit 	<ul style="list-style-type: none"> • verify coped section is strong enough • connecting element: double angles • can use all bolts, all welds, or weld at girder and bolt at beam
	S6 <ul style="list-style-type: none"> • connecting element: angle • weld at girder, bolt at beam • check limit states of connection 	<ul style="list-style-type: none"> • verify coped section is strong enough • same connection detail as Activity 1
	S8 <ul style="list-style-type: none"> • connecting element: angle • weld at girder, bolt at beam • check limit states of connection 	<ul style="list-style-type: none"> • verify coped section is strong enough • same connection detail as Activity 1
"Text Condition" (T Group)	T1 <ul style="list-style-type: none"> • connecting element: single or double angles • used bolts at beam and girder 	<ul style="list-style-type: none"> • same connection detail as Activity 1
	T3 <ul style="list-style-type: none"> • connecting element: double angles • used bolts at beam and girder • check block shear 	<ul style="list-style-type: none"> • same connection detail as Activity 1 but could use weld at beam and girder
	T5 <ul style="list-style-type: none"> • not sure how to attach beam to girder • read mostly single angle • check limit states 	<ul style="list-style-type: none"> • connection at web • not sure how to attach beam to girder
	T7 <ul style="list-style-type: none"> • connecting element: angle • used bolts at beam and girder • not enough knowledge on weld • check limit states on bolts 	<ul style="list-style-type: none"> • connecting element: double angles • used bolts at beam and girder or weld at beam and bolt at girder • pre-attach double angles to beam first, then connect to girder

Table 1. Summary of Responses to Beam Attachments

large – 50 students per class in an introductory level steel design course is not unusual – a lot of cardboard beams and girders would have to be made.

Furthermore, on average, it takes 15 to 20 minutes for each team to perform the activities. If activities for other connection types are desired, more cardboard members would be needed. Depending on the connection types included in the student activities, some of the members cannot be salvaged after the activity. For example, in the assessment process conducted by the Searle Center researcher, we asked the students to do the beam bracing activity first followed by the floor system activity. Since activity 1 did not require any coping, the beam was used in the second activity. If these two activities were reversed in order, additional 8 beams would have been made for our assessment.

Owing to the multiple shortcomings of using cardboard members to assess the students' learning, a set of online quizzes was de-

veloped to cover the majority of the connection types and situations represented in the sculpture. Figure 15 shows an example of an online quiz and table

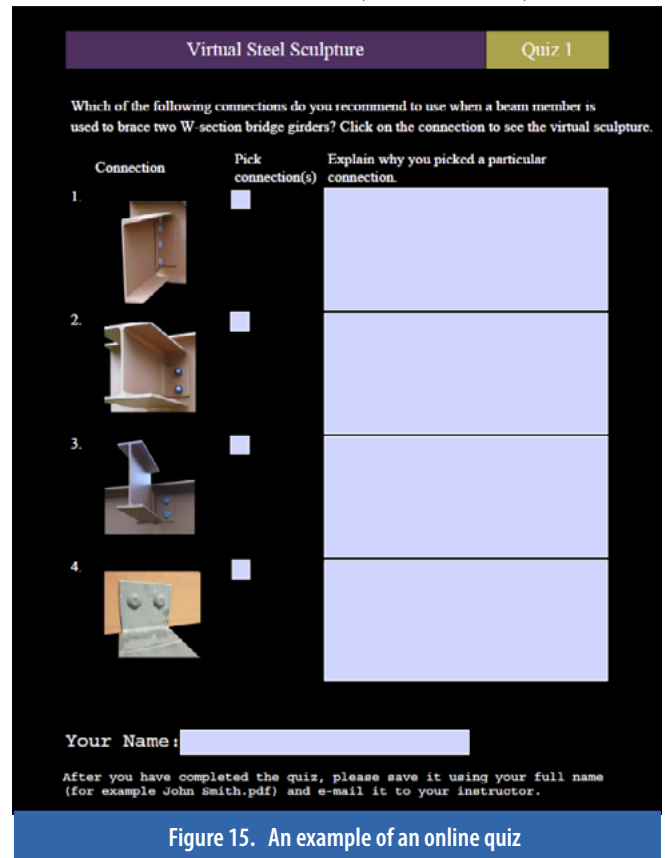


Figure 15. An example of an online quiz

2 lists the situation in each quiz for the students to select the connection(s) they would recommend for the situation. For each situation, 4 connection choices selected from the Sculpture are given. The students are asked to pick their recommended choice(s) and write a brief explanation to justify each of their selection(s). The number of acceptable choices varies among quizzes. To help the user recall the connections, he or she can click on each of the connection to see more detail. Each connection choice in a quiz is hyperlinked to the Virtual Steel Sculpture at the place where the connection is located in the Sculpture. By clicking on the connection, a new window is opened and additional information such as the blue print drawing^[1], sample calculations^[3], field examples^[1], and finite element analysis^[2] can be studied.

The primary objective of the sculpture, both physical and virtual, is to provide a visual aid for the students and instructors on the assembly of structural members for various types of connection. Hence, the quizzes are focused on the students' ability to select the proper connection assemblies to meet a specific structural function. The purpose of each connection situation and the options an instructor has in utilizing these quizzes are described in subsequent sections.

Quiz 1 – *which of the following connections would you recommend when a beam member is used to brace two W-section bridge girders?*

This quiz is the same as Activity 1 that was used in the assessment process with the cardboard members. It is one of the more common connection types seen in bridge bracing to support lateral stability of the long bridge girders. The quiz provides two acceptable choices. However, there are additional ways to provide bracing that is not available in the Sculpture. (See field examples of connections 5 and 6 of the Virtual Sculpture or choices 1 and 2 in the quiz.)

Quiz 2 – *which of the following would you recommend when you have a concrete slab that is bonded to the beam and behaves as a composite section?*

Composite sections are commonly used in bridges as well as floor decks with higher than normal floor live load. The shear studs are the connectors that tie the concrete slab to the steel beam to form a T-shape cross section for the beam. The composite section takes advantage of the compressive strength of concrete and yields a higher bending moment capacity.

Quiz 3 – *which of the following would you recommend when two beams are spliced to create one continuous beam?*

Beam splices are used for long span beams when the beam length is longer than that for safe and feasible transportation from the fabricator to the construction site, and for safe erection. Beam splices are quite common

Quiz	Question
<i>Which of the following connections would you recommend</i>	
1	when a beam member is used to brace two W-section bridge girders?
2	when you have a concrete slab that is bonded to the beam and behaves as a composite section?
3	when two beams are spliced to create one continuous beam?
4	when a floor beam is connecting to a girder. Note that the beam and girder are used to support a floor slab?
5	when a column requires support from the foundation?
6	when you need to brace a frame from lateral forces such as wind or earthquake?
7	when two columns are spliced to create one continuous column?
8	when a joist needs support?
9	when you want a simple shear connection between a beam and the web of a W-section column?
10	when you need a shear-moment connection?
11	when you need a simple shear tab connection between two beam members?
12	when you need a simple shear tab connection between two beam members but do not want to cope the beam?

Table 2. Member connection situation for each quiz

on bridge girders. The critical factor in beam splices is to maintain the continuity of the beam in axial, shear, moment, and deflection. Hence, shear-moment connection is used. The distinct characteristic of a moment transfer connection is that both flanges of one beam are connected to the flanges of another beam.

Quiz 4 – *which of the following would you recommend when a floor beam is connecting to a girder? Note that the beam and girder are used to support a floor slab.*

This quiz is the same as Activity 2 that was used in the assessment process. It is very common to use floor beams to transfer floor loads to the girder. Unlike Quiz 1, the critical element here is that the top flanges of the floor beams and the girder have to be flushed. Hence, coping of the beam top flange and part of the beam web is necessary. Figures 8 to 10 show the correct way of connecting the beam to the girder while Figures 11 to 14 show the perceptions students have for this connection.

Quiz 5 – *which of the following would you recommend when a column requires support from the foundation?*

Spread footing is one of the most cost effective foundation types to support a structure. However, in order to use this type of foundation, the soil bearing capacity must be high enough to support the loads applied within tolerance limit in deflections. When steel columns are used to transfer the load from the super-structure to the sub-structure, and the soil bearing capacity is high enough, spread footing is often used. The anchorage (connection) of the column to the footing is provided by the anchor bolts through the base plate.

Quiz 6 – *which of the following would you recommend when you need to brace a frame from lateral forces such as wind or earthquake?*

When braces can be provided in a steel frame structure, both the design and construction could be a lot simpler than when a moment frame is required. Structural,

architectural, fabrication, and erection requirements or restrictions may warrant the use of moment frames. It is also not uncommon to use both a moment frame and braces to support lateral forces. The intent of this quiz is to see if the learner can recognize a brace connection. There are multiple ways, such as diagonal, X, chevron, or knee, bracing can be provided. Diagonal and X braces are more effective. However, openings for windows, doors, and other elements may prevent the use of these braces. In addition, brace members are not restricted to HSS sections as shown in the sculpture. Single angle, double angle, and WT are other common sections used for braces.

Quiz 7 – *which of the following would you recommend when two columns are spliced to create one continuous column?*

Like beam splices, column splices are used for mid to high rise buildings where the column length needed to extend the full height of the building is longer than that for safe and feasible transportation from the fabricator to the construction site, and for safe erection. It is important to realize that one should not splice the column at floor height. AISC has a recommendation on the minimum distance between the floor elevation and the column splice. Like the beam splice, the critical factor in column splices is to maintain the continuity of the column in axial, shear, moment, and deflection. The distinct characteristic of a moment transfer connection is that both flanges of the lower column are connected to the flanges of the upper column.

Quiz 8 – *which of the following would you recommend when a joist needs support?*

Steel Joist Institute (SJI), like AISC, is an organization representing the steel joist industry and responsible for the specifications associated with steel joists design and their support. SJI specifications include the weld (weld length and weld size) or bolt (bolt size and bolt arrangement) connections of the joist to the steel members.

The specifications often influence the beam selection to accommodate the minimum flange width needed to support the joist. Structural engineers usually consult SJI specifications or joist suppliers on joist selection and connection requirements.

Quiz 9 – *which of the following would you recommend when you want a simple shear connection between a beam and the web of a W-section column?*

Simple Shear Connection is what we idealize as a hinge in elastic analysis. Simple shear connection can be located at the junction between beam and column, between a beam and a girder, or between two portions of a beam. This quiz focuses on the simple shear connection of the first case. Simple shear connection is very common for low-rise buildings with minimal lateral loads or when lateral loads can be resisted using braced members.

Quiz 10 – *which of the following would you recommend when you need the shear-moment connection?*

Shear-Moment Connection is used whenever we want to transmit axial, shear, and moment from one member to another member. Both Quizzes 3 and 7 are a special use of this connection type. For a moment frame, the connection between a beam and a column is a shear-moment connection. Connections 33 and 34 (choice 2) are used in moment frame while connections 23 and 24 (choice 1) are used in beam splices. The distinct characteristic of a moment connection is that both top and bottom flanges of a beam are connected to the column or another beam member.

Quiz 11 – *which of the following would you recommend when you need a simple shear tab connection between two beam members?*

Simple Shear Connection is what we idealize as a hinge in elastic analysis. Simple shear connection can be located at the junction between a beam and a column, between a beam and a girder, or a few feet from the end of a beam. This quiz focuses on the middle case where the beam and the girder are in different vertical planes. The situations described in Quizzes 1 and 4 are a subset of this Quiz.

Quiz 12 – *which of the following would you recommend when you need a simple shear tab connection between two beam members but do not want to cope the beam?*

The purpose of this situation is the same as Quiz 11. The difference here is the size of the tab (connector) used to connect between the two members. In Quiz 11, the shear tab is short so that the connection only has shear action. In Quiz 12, with a longer shear tab, coping can be avoided. However, the longer shear tab would create moment between two connecting members.

The situations described in the set of quizzes represent the majority of connections used in regular bridge

and building designs. For students who do not have the opportunity to take additional courses in steel design and for faculty who would like to expose the students to some common connections that students may encounter upon graduation, the Virtual Steel Sculpture and the quizzes would give students an excellent introduction to the function, assembly, and application of these connections.

For the instructors, the Virtual Steel Sculpture and the quizzes offer a glimpse of steel connections used in the industry. The 48 connections included, while more than in the original sculpture, are by no means an exhaustive list. For example, in practice, we have interchanged the use of welds and bolts; used double-angles instead of WT or HSS sections for bracing, etc. These are not all reflected in the Sculpture. Choices often depend on the project, geographical location (contractor's preference), availability, ease of construction, and so on. The instructors have all the flexibility on how they would like to use the Sculpture and/or quizzes to facilitate student learning. The instructors can also develop new activities to assess their students' learning. AISC Web Enhanced Teaching (WET) of Structural Steel https://sites.google.com/a/aisc.org/educator_forum/?pli=1 is a forum where instructors can share their teaching ideas.

Survey forms

Three slightly different online survey forms were also developed with the contribution from the Searle Center researcher. Each survey form was designed for different groups of users: students, instructors, and newly minted engineers. The first part of the survey is identical for all three forms. The survey questions pertain to the Sculpture. The remaining part of the survey is customized for each group of users. For the first part the questions are:

1. Please rate the Virtual Steel Sculpture webpage in the following areas:
 - 1.1. The layout of the webpage
 - 1.2. The visual design of the webpage
 - 1.3. The organization of information
 - 1.4. The ease of navigation in finding information
 - 1.5. The visual quality of tutorial videos
 - 1.6. The audio quality of the tutorial videos
 - 1.7. The ease of understanding the content of tutorial videos
 - 1.8. The quality of the content of tutorial videos
 - 1.9. The ease of downloading files
2. Please rate the interactive Virtual Steel Sculpture (the interactive 3D pdf file) in the following areas:
 - 2.1. Rotation capabilities
 - 2.2. Zooming capabilities
 - 2.3. Isolating a connection capabilities
 - 2.4. The ease of navigation to view a connection from different angles
 - 2.5. The ease of navigation to view different connection types

3. Please rate the 2D pdf file for each connection in the following areas:
 - 3.1. The ease of navigation to obtain information for a connection
 - 3.2. Clarity of blueprint
 - 3.3. Helpfulness of blueprint in illustrating the connection assembly
 - 3.4. Clarity of close-up views
 - 3.5. Helpfulness of close-up views in illustrating the connection assembly
 - 3.6. Clarity of field examples
 - 3.7. Helpfulness of field examples in illustrating the application of connections
 - 3.8. Organization of sample calculations
 - 3.9. Helpfulness of sample calculations in illustrating the procedures to determine connection capacity
 - 3.10. Ease of understanding of finite element analysis (FEA) results
 - 3.11. Helpfulness of FEA in illustrating the stress distribution in connecting components
4. Please rate the sample calculations in the following areas:
 - 4.1. The clarity of connection description
 - 4.2. The clarity of references to AISC specifications
 - 4.3. The clarity of schematic drawings
 - 4.4. The helpfulness of schematic drawings in supporting the calculation procedures
 - 4.5. The clarity of sample calculation steps
5. Please rate the effectiveness of the Virtual Steel Sculpture in enhancing your understanding of connection types, assembly, and accessibility:
 - 5.1. Tension connection
 - 5.2. Shear connection
 - 5.3. Shear-Moment connections
 - 5.4. How connections are assembled (need for coping, etc.)
 - 5.5. Allowance for mechanical/electrical conduits

The remaining part of the survey pertains to the user group's background information. For the student group, the survey questions focus on their major, academic classification (senior, MS, etc.), number of steel design courses taken, and how frequently they used the Virtual Steel Sculpture. For the newly minted engineer group, the survey questions include: their educational background on steel design, and whether they used a physical steel sculpture in their education. For the instructor group, the survey questions include: the presence of a physical steel sculpture on their campuses, the incorporation of the steel sculpture in courses they taught, and the likelihood that they would incorporate the Virtual Steel Sculpture in the following ways in their course(s):

1. As part of their steel connection design lectures
2. As self-learning supplement in the introductory (first) steel design course when the connection type(s) are taught

3. As self-learning reference in the introductory (first) steel design course when the connection type(s) are NOT taught
4. As self-learning supplement in advanced level (beyond the first course) steel design courses when the connection type(s) are taught
5. As self-learning reference in advanced level (beyond the first course) steel design courses when the connection type(s) are NOT taught
6. As self-learning reference for the senior capstone design project
7. As self-learning reference for MS level design project
8. Other courses/lectures

Both the newly minted engineer and instructor groups were polled on their interest in having a workshop (about one-hour) on the Virtual Steel Sculpture in technical or ASEE conference.

Student survey result – seventeen students from a structural steel design class were surveyed (with 16 responses) after the class had an opportunity to self-learn a simple shear connection using the Virtual Steel Sculpture and textbook. This group of students also participated in the hands-on learning assessment project as described in the *Assessment Process* section above. At the time of the assessment, the students were given a book chapter on connection design which covers many connection types and one sample of the shear connection type (connection 1) in detail from the Virtual Sculpture. The survey questions were: (1) learning the design calculations; (2) application of the connection; and (3) assembly of the connection. For each question, the students were asked to rate the likelihood (5 for definitely likely and 1 for definitely unlikely) of using each of the choices: Virtual Steel Sculpture, textbook, and combination of both. The results are summarized in table 3.

Another set of questions was on the Sculpture and the text book as learning sources: if one medium is chosen as the primary learning source, how likely is the second source to be used as a supplement. This survey clearly indicated the following:

- The Virtual Steel Sculpture is a preferred visual aid to student learning and the textbook is the clear choice for learning design calculation with the Sculpture as a supplement.
- When only given one source to learn to design a connection, there was a slight preference (9 to 7) for the Sculpture over the textbook. Visualization was the main reason for choosing the Sculpture while familiarity with textbook format, multiple connection type examples were the reasons for selecting the textbook.
- Students prefer to have both the textbook and the Sculpture as their resources for learning (questions 4 and 5 in Table 3). The smaller standard deviation in questions 5 indicated that the preference of the students to have the sculpture to supplement their current resource is very similar.

It is worthwhile noting that at the time of this survey, the 2D pdf file was only available for one connection (the one the students used for the assessment activities) and the finite element analysis for the stress distribution was not available for that connection. We expect the survey outcome would be different now that the entire Virtual Steel Sculpture is fully functional.

Conclusions

The effectiveness of the Virtual Steel Sculpture was assessed through hands-on activities using cardboard members developed by the steel course instructor (one of the project PI) and conducted by the researcher from the Northwestern University Searle Center for the Advancement of Teaching and Learning (Searle Center). The assessment included two groups of students from the same class. One group was asked to learn the shear connection through the Virtual Steel Sculpture while the second group was given material from the textbook on shear connection design. The assessment showed that the students understood how a braced beam is connected to a girder. However, there was a distinct difference between the two groups when they were asked to connect the same beam and girder to form a floor system. The group as-

signed to study the Sculpture understood how the beam and girder should be connected in a floor system while the group that studied the connection using the textbook clearly had a difficult time recognizing the need for coping in order to form a leveled surface. This study obviously provides only a preliminary assessment of the impact of the Sculpture on students' understanding of connections. Further studies with a larger number of students and a diverse range of assessment activities are required. Future studies should use think aloud protocols to examine students' thought processes as they perform the connection activities. Students should be interviewed about how they interacted with the Virtual Steel Sculpture and about any particular aspects of the Sculpture that seem to enhance their learning.

The same group of students participated in the assessment process and was asked to complete a survey form regarding learning a simple connection design using both the textbook and the Virtual Steel Sculpture. Preferences for the two resources were very close. With respect to attributes of design: calculations, applications, and assembly, visualization there was a slight preference for the Sculpture except for calculations where the textbook is preferred. However, when only allowed one resource to learn the design, 9 chose the Sculpture and 7 chose the textbook. According to the students' comments, those who chose the textbook as their primary source of learning cited the familiarity of the textbook format and the number of connection types discussed in the text. At the time of this assessment process and survey, only one complete 2D pdf was available for the students to learn one connection design. Now that the Sculpture is fully interactive and all the features are available, the survey outcome may change.

The cardboard member activities led the project investigators to develop a set of online quizzes to help instructors assess their students' learning outcomes related to the Sculpture. These quizzes cover majority of the connections shown in the sculpture. Multiple connection choices may be acceptable for each situation presented in the quizzes. Instructors may choose to ask the students to simply select the acceptable connection choice(s) for each quiz or to include justification for their choices. The instructors may also ask more in depth questions associated with each connection choice. These quizzes were designed so that the instructors have wide latitude on the learning outcomes they wish to assess.

Disclaimer

Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the National Science Foundation. NSF has not approved or endorsed its content.

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		average	standard deviation	
1.	learning the design calculations using	Virtual Steel Sculpture	2.9	2.1
		textbook	4.0	3.6
		combination of both	3.2	2.9
2.	application of the connection using	Virtual Steel Sculpture	3.7	3.6
		textbook	3.2	3.1
		combination of both	3.0	2.3
3.	assembly of the connection using	Virtual Steel Sculpture	3.8	3.4
		textbook	3.1	2.5
		combination of both	3.6	2.8
4.	primary resource	Virtual Steel Sculpture	3.6	3.5
	supplementary resource	textbook		
5.	primary resource	textbook	3.6	2.4
	supplementary resource	Virtual Steel Sculpture		

Table 3. Summary of survey statistics from 1 class of 17 students with 16 surveys collected in the introductory steel design class.

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