Pushing and Shoving: Improving Student Understanding of Support Reactions with Hands-on Demonstrations

Dr. Tonya Lynn Nilsson P.E., Santa Clara University

Tonya Nilsson is a Senior Lecturer in Civil Engineering at Santa Clara University (SCU), where she regularly facilitates pedagogical training for other faculty. Prior to joining SCU, Tonya was an Associate Professor at CSU - Chico.

Dr. Laura Doyle, Santa Clara University

Dr. Laura Doyle is a lecturer in the Civil Engineering Department at Santa Clara University where she teaches undergraduate courses in civil engineers. Before coming to SCU, Laura was a post doctoral scholar for the John Muir Institute of the Environment at University of California, Davis where she used multi-dimensional models to examine water quality of the San Francisco Bay Delta system. She earned her masters and doctoral degrees at UC Davis and her undergraduate degree (all in civil engineering) is from Loyola Marymount University.

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Abstract
Understanding support reactions and developing an intuitive feel for what behavior each connection type (fixed, pinned, bearing, etc.) actually represents remains a continuing challenge for statics students. To improve students' grasp of this important concept, 3D connections are introduced via a highly active class session that requires students to move in pairs through five stations to physically interact with common supports. Students are provided an activity sheet that guides them through the stations. For each station, the activity sheet includes images of real-life applications of the connection type, the common schematics/drawings used to represent the connection type in statics problems, and the start of a free body diagram, FBD, where the student is directed to draw their perceived support reactions after interacting with and loading the demo. To further reinforce their knowledge gain, students are required to reflect and indicate where they have seen this connection type outside of the classroom. The demos are followed by four 3D examples where students work in their pairs to draw the FBD. A survey conducted in five statics courses taught by the authors found that 75.3% of student respondents (n = 78) indicated this activity was helpful in their understanding of support reactions with only 9.1% saying it had no impact and 15.6% indicating it was only a little helpful.

Introduction
The ability to accurately solve statics problems is critical for engineers in a wide variety of fields including civil, mechanical, aerospace and bio-engineering. Fundamental to determining statically correct solutions is the accurate determination of support reactions. Separate studies by Stief [1] and Call, *et al,* [2] found students struggled with determining the correct support reactions to include on a free body diagram, which is unlikely to surprise engineering faculty who have taught the course. Work by Litzinger, *et al,* [3] looked deeper into the actual problem solving approach of students in statics. They found that the majority of students, all of the weak and most of the strong, identified support reactions based purely on memory and that only a few students would try to reason out the support reactions based on expected physical behaviors. Having made these same observations, the authors endeavored to create a lesson module that would support student's development of an intuitive feel for 3D connection behavior and ability to reason out the 3D physical reactions.

There is significant research on the importance of linking new knowledge to existing knowledge to create durable learning, especially when the existing knowledge is learned experientially [4] – [7]. The research also indicates new material that relates to existing knowledge is less likely to cause fear or anxiety in the learner, which improves learning [8], [9]. The opportunity to reflect on and write about one's own understanding of the new material has also been found to support knowledge development [10]. Finally, distributed practice has been shown to be significantly more effective than massed practice [11]. With this in mind, the authors attempted to create a lesson module for 3D support reactions that incorporated best practices in student learning.

Lesson Module Description
The lesson module created for 3D support reactions contained the following learning objectives:

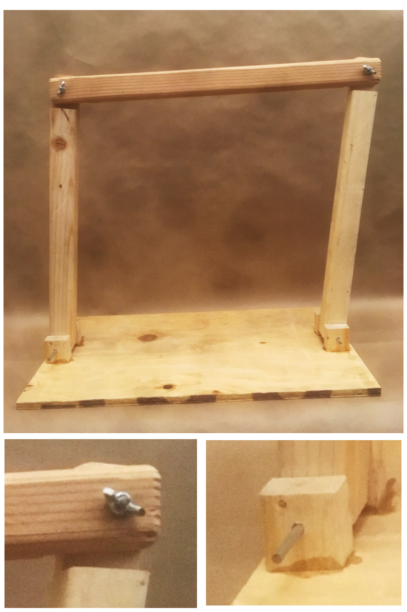
1. identify and determine support reactions in 3D structural supports,

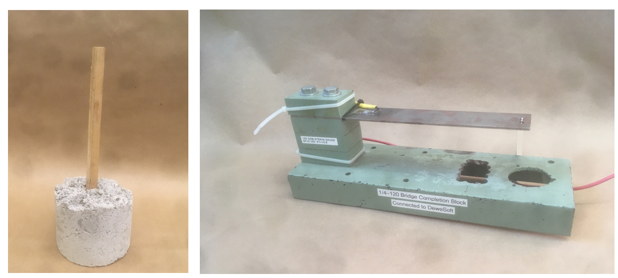
2. determine if a 3D body has redundant supports, i.e. is statically indeterminate, and
3. determine if a 3D body is properly constrained, i.e. is it able to resist all possible motions or is it improperly or partially constrained?

To meet these objectives, the students had a pre-class assignment; hands-on activities, team problem solving and reflective writing during class; and a homework assignment due at the following class meeting.

The pre-class assignment required students to read the course textbook section on 3D supports, which included images of supports and their possible reactions. To encourage students to do the reading, a short on-line quiz was assigned that was due before the start of class. The pre-class assignment was included to facilitate distributed learning and to ensure that students' first exposure to 3D support reactions was not at the start of the lecture period.

At the start of class, students were paired into teams of two and provided with an activity handout, which is provided in the Appendix. The activity required students to visit stations around the room that had physical models of five different 3D supports. The models are easily transportable to class with a small cart and students helped distribute the models around the classroom during the ten-minute transition period between classes. The five support types were rollers – with and without friction, pins, fixed connections, ball and socket joints, and journal bearings. The two types of rollers were easily modeled using chairs with and without wheels that were already in the classroom. Photographs of the remaining models are provided in Figure 1.





(b) Fixed base 'post' and cantilevered beam for fixed connection.

(a) Pinned frame showing slightly rotated position, with wingnut at top and pinned dowel at the base.

(c) Single ball and socket joint mounted on a wood block.

(d) Single journal bearing mounted on a wood block.

Figure 1: Physical models used to demonstrate (a) pin connections, (b) fixed connections, (c) ball and socket joints, and (d) journal bearings.

The first 35 minutes of the 65-minute class period was reserved for students to move through the stations at their own pace. Students were instructed to read the handout description of the connection type at each station, which included photos of real-world applications of the support and examples of common places the connection type could be found. Students were told to impose forces and moments about each axis of the model and determine if the support could resist the applied loading. The handout included a drawing with a structural member supported by the symbolic or schematic representation of the connection and the start of the corresponding free body diagram with the support removed but no support reactions drawn. An example of this activity for a pin connection is shown in Figure 2. After interacting with the physical model, students were required to draw what they believed were the possible support reactions for that connection type and they were required to reflect back on their own experiences and identify other objects that use the connection type. To hold the students accountable for the work, they were told they should be prepared to report out their answers and the instructors checked in with pairs to answer questions and review proposed support reactions on the FBDs.

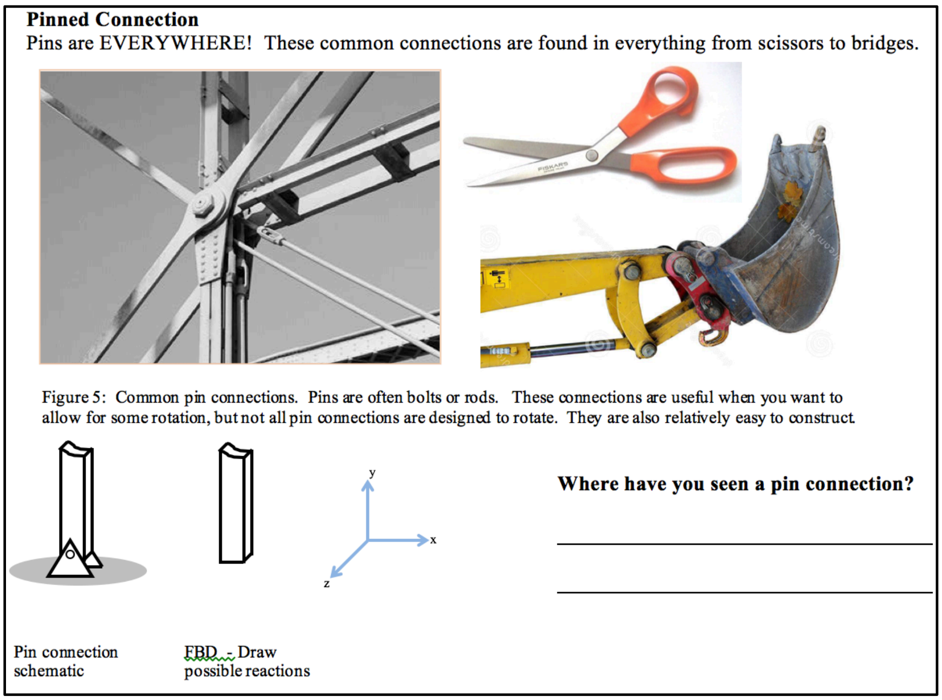


Figure 2: Lesson handout excerpt with guided activity to investigate pin connections. Students complete this activity while physically interacting with the pinned frame shown in Figure 1a .

After a team visited all five stations, they were required to reflect on connection types in general and answer the following written questions:

1. Has this activity addressed every possible connection or support type? Explain your answer.
2. If you were presented with the schematic of different connection or support type, how would you determine the possible support reactions?
3. The handout purposely uses the language “Draw possible reactions” for each free body diagram instead of “Draw reactions”. Why did your instructor purposefully write this?

Student generally took five minutes to complete this reflection.

The final time in class was spent drawing free body diagrams for 3D practice problems taken from the course text book. For each problem students were asked to:

1. Draw the free body diagram.
2. Identify the number of unknown support reactions.
3. Identify the number of available equilibrium equations.
4. Indicate if the system is determinate and explain why or why not.
5. Indicate if the system is stable and explain why or why not.

To reinforce their knowledge gain, homework due the next class meeting included practice problems to identify 3D support reactions. To encourage students to look for more real-world examples of standard connection types, the lesson homework also required the students look around their everyday environment and find an example of a pin or hinge support and a fixed support. The assignment required a photo of each support and a hand drawn free body diagram with the support reactions.

Student Perceptions

The authors have implemented this lesson module in a combined total of five sections of statics. At the end of each course, students were asked to complete an on-line course survey to provide feedback on various course components including this in-class activity. On average about 90% of students in each section completed the survey but closer to 60% gave permission for their results to be included in published work resulting in n = 78.

The students were asked to indicate the effect of the 3D support activity on their understanding of the concept with the option to answer: "Made no impact or I don't remember", "Helped, but just a little", "Somewhat helpful", "Helpful, added to my understanding", or 'It is why I understood the topic". Across all five sections, 75.3% indicated the activity was at least 'Somewhat helpful'. Only 9.1% indicated the activity 'Made no impact or I don't remember', while 15.3% indicated it 'Helped, but just a little'. It is not clear if the students who answered 'Made no impact or I don't remember' were not in class for the lesson or if the activity made no contribution to their learning. Of the 75.3% who indicated the activity was helpful, 40.3% noted the activity was 'Helpful, added to my understanding' and 9.1% indicated 'It was why I understood the topic'. The remaining 26.0% found the activity 'Somewhat helpful'.

If the above information is converted into a Likert scale, where "Made no impact or I don't remember" equals 1 and "It is why I understood the topic" equals 5, the average response is 3.25, or helpful, across the five sections. Male students (n=52) found the activity helpful but slightly less so than female students with an average response of 3.17. Female students (n=26) found the activity more helpful with an average response of 3.4, which may be explained by less experience interacting with models, tools, or machines growing up. Studies into children's toys have found that toys culturally viewed as being for girls are less likely to build spatial skills for STEM careers or support knowledge gain in mechanics [12] – [14].

It is important to note that two additional faculty also implemented this module in one section of statics each. These faculty have minimal experience and training in teaching with active-learning pedagogies. The faculty were given written directions, i.e. lesson notes, and some verbal instruction for conducting the very active module, but did not personally watch the authors teach the lesson and were given no specific training in active pedagogies. Combined survey responses from their sections found 56.7% of students indicated the activity ‘Made no impact or I don’t remember’ or ‘Helped, but only just a little’. Less than 24% found the activity ‘Helpful, added to my understanding’ or ‘It was why I understood the topic’. The Likert scale average was 2.4 (n = 31), which indicates the activity was not viewed as helpful. Again, female students rated the activity higher with an average rating of 2.75 versus 2.17 for male students. The data set for these sections only includes eight female students, which alone is too small, but the trend of female students finding the activity more helpful than males students is in line with the responses from the authors’ sections.

Module Delivery

Berstein [15] reports on the findings of multiple studies that determined faculty training in the use of active-learning pedagogies had a significant impact on the effectiveness of active-learning modules in the classroom. The authors of the current study designed this learning module with the intent that the faculty member teaching the lesson would actively engage the students through the entire class period. Post course interviews with the two additional faculty who implemented this lesson in their courses determined they were significantly less engaged with the students than the authors intended, with one indicating he simply handed out the handouts and let the students work. This was a lost opportunity by the authors as these two faculty had expressed a willingness and an interest in implementing a new teaching methodology in their classroom. Although written instructions were provided, it is clear the lack of an example or demonstration of best practices in active teaching resulted in an experience for both the instructors and students that was less positive than necessary. As such, it is recommended that readers who have limited experience in active teaching methodologies but who are interested in adapting this activity in their own class read the delivery instructions provided in the Appendix and seek out instruction or guidance in active pedagogies from experienced colleagues or their university’s teaching and learning center.

Summary

The described 3D support reactions lesson module contributed to student learning and was well received by students taught by faculty members who were skilled and experienced in active-learning pedagogies. The ability to engage the students during the activity had a significant impact on student perception. Students who were assigned the activity with minimal accountability or faculty interaction reported the activity provided little help in their knowledge gain. Anecdotally the authors found their students had an improved grasp of expected reactions and that students would reflect back on the lesson activity to visualize support reactions instead of depending purely on memorization. A study of the students’ cognitive problem-solving approach was not conducted to confirm this observation.

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Appendix

Delivering the module to the class:

Prior to class:

- Remind students to bring their textbook to class or include textbook problems in the lesson handout for Activity 2.
- Load all but the roller connection models on a cart to transport to class.
- Use chairs in the classroom for the roller connection.
- Ask students to help distribute models around the classroom before class begins.

First 30 - 35 minutes:

- Instruct students to read the handout and work in pairs to complete the FBD's for the five model connections. Regularly remind students to physically interact with the models.
- Regularly check in with students to:
    - Answer questions they might have at a connection station.
    - Verify they are doing the work and their FBD drawings are accurate.
    - Manage students who finish quickly by requiring them to find the support reactions for the first problem assigned in activity 2.
- During this time, the faculty member should also pre-place free body diagrams, minus the support reactions, on the white boards for the five connection types and the textbook practice problems. As an alternative to drawing on the boards during the activity time:
    - Draw the FBD's in advance on poster size post-its.
    - Draw the FBD's electronically and print on 11x17 sheets that can be taped to walls or placed on white boards with magnets.

At 30 - 35 minutes:

Verify all students have the correct reactions by drawing the supports on the pre-posted FBD's:

- The instructor could draw the supports by calling on students for the correct answers.
- The instructor could call five teams simultaneously to the boards – one per activity FBD – to draw their correct answer on the FBD. By checking in with students in the first 30 minutes, the instructor can identify teams with correct FBD's to send to the board.

Answer any outstanding questions from students before the students complete the reflection.

Remaining time:

The remainder of the class period is spent determining the support reactions for the assigned textbook practice problems. For each problem, give students one or two minutes to think about the possible reactions and then call on students to help you complete the FBD for that problem, which you already have pre-posted. With an accurate FBD completed, then ask the students the four questions regarding determinacy and stability, which should be review from 2D problems.

If you are not able to complete all four practice problems, post the solutions for the students to review on their own.

End of class:

Ask the students to help you reload the cart and take down the pre-posted FBDs.

Lesson 12 – Activity 1 – Page 1
Support Reactions in a 3-D world

There are numerous types of connections and supports. As an engineer, you need to be able to determine whether the support or connection can resist applied forces and moments.

In 3-D, the six possible components of the resultant support moment and support force are F_x, F_y, F_z, M_x, M_y, and M_z, see Figure 1.

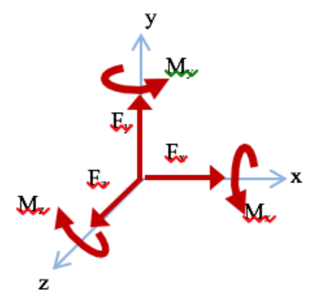


Figure 1: Six possible support reactions (scalar components of a resultant moment, **M,** and force vector, **F.**

YOUR TASK:

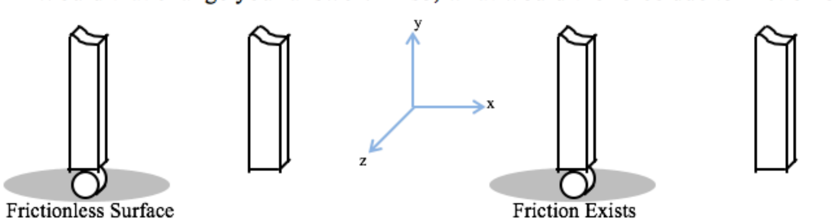
- Working in groups of 2, visit each of the five stations and interact with the objects.
- Impose forces and moments about each axis and determine if the support or connection is able to resist your imposed loads.
- Using the provided schematics and FBD's, draw the possible reactions that support or connection could develop. You do not have to visit the stations in order.
- ***Be prepared to report out your answers.***

Roller/Bearing on a frictionless surface, also Rocker Bearings:

Rollers and bearings are very common in bridge design. Chairs also bear on the floor, with or without wheels (rollers). (FYI – Bearing, as a verb, means to bear or rest upon. Bearing as a noun is often associated with supports that allow rotation, like ball bearings.)

Figure 2: Two bearing bridge connections to allow for thermal expansion. The left bridge uses a rocker bearing and the right bridge is supported on a roller bearing.

Assuming the bearing occurs on a frictionless surface, draw the support reaction(s) that can develop in a roller (or rocker, it would be the same). What if the surface wasn't frictionless? Say you had a chair on carpet? Would that change your answer? If so, what would the force due to friction equal?



Frictionless Roller schematic	FBD - Draw possible reactions	Roller with friction schematic	FBD – Draw possible reactions

Another example of roller or bearing?

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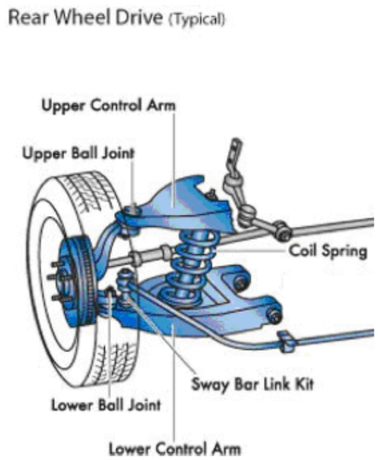
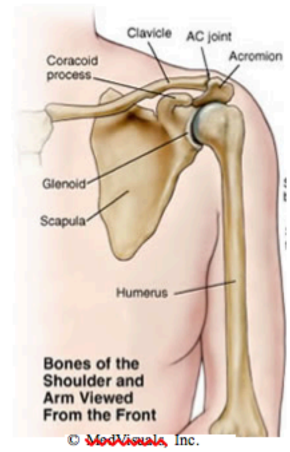
Ball and socket joint:
Both the shoulder and the hip are ball and socket joints. Tires are connected to the car frame with one or two ball joints, depending on drive type.

Ball and Socket schematic





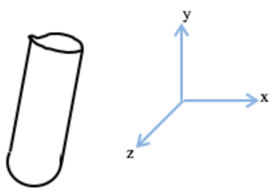


Figure 3: Rear wheel drive cars typically have both an upper and lower ball joint on the driving tires, while front wheel drive cars only have one ball joint at each driving tire. The human body has a ball and socket joint at both the hip and the shoulder.

Give another example of a ball and socket joint.

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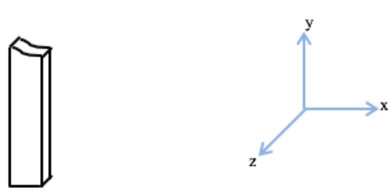
FBD – Draw possible reactions

Fixed Connections:
Common items like street lights, stop signs and diving boards all used supports that provide fixity.

Fixed connection, possible schematics



FBD - Draw possible reactions

Figure 4: Fixed connections are key to any cantilevered member, whether it is a horizontal or vertical member.

Where have you seen this? Give a different example.

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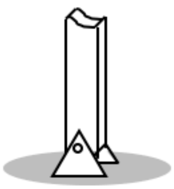
Pinned Connection

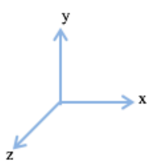
Pins are EVERYWHERE! These common connections are found in everything from scissors to bridges.

Figure 5: Common pin connections. Pins are often bolts or rods. These connections are useful when you want to allow for some rotation, but not all pin connections are designed to rotate. They are also relatively easy to construct.



Pin connection schematic

FBD - Draw possible reactions



Where have you seen a pin connection?

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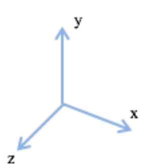
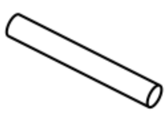
Single Journal Bearings

Bearings are a critical support for machinery, motors and any object with a rotating shaft. The two common types of single bearings are journal-bearings and thrust-bearings. This section deals with journal-bearings. Thrust bearings look identical but can resist force along the shaft (x-direction).

Journal-bearing schematic





FBD - Draw possible reactions

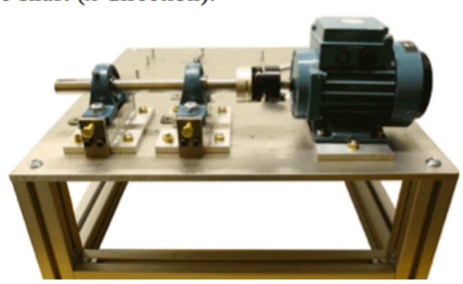


Figure 6: The motor on the right turns the circular shaft that could be attached to any number of machines like lathes, mills, etc. Single journal-bearings support the circular shaft at two locations along its length.

Give an example where you have seen a journal-bearing. ________________________________

Thought question: Can the bearing resist bending about the y and z axes? Try it. Under normal use (see the picture), should these moments ever develop?

So What???

Has this activity covered every possible connection or support type? Explain your answer. ____________

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If you were presented with the schematic of a different connection or support type, how would you determine the possible support reactions?

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Why does the language for all the FBD's say "the 'possible' support reactions" and not just "the support reactions"?

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