Roles of visual understanding in developing conceptual understanding of structural principles

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Abstract

The structural engineer must be able to conceptualize through a lens of both qualitative and quantitative structural performance. Basically, this means that structural engineering students need to have a *flexible* mathematical understanding to use their knowledge as a tool to solve engineering problems. Although accuracy and reliability in solving quantitative problems is necessary, a qualitative understanding is also required in applying structural concepts and principles to various practical situations, especially when the structural form is unconventional or innovative. In order to develop the genuine conceptual understanding of structural principles and theories that underlies structural forms, students must actively engage in procreative mental activity coupled with interpretation of personal observation and experience. However, if the students remain as passive listeners in structural classes, such activity is rarely induced. The students become to pay more attention to problem solving technique without being attentive to the underlying concepts. In an effort to find balance and connection, and increase awareness of the interrelationship between quantitative and qualitative understanding in the structure classes, a unique teaching methodology including combined visual and mathematical understanding has been developed and used. The contents, sequence and rationale of the approaches are described in this paper.

Introduction

"Mechanics is the paradise of the mathematical sciences, because by means of it one comes to the fruits of mathematics." – Leonardo da Vinci

An intensive mathematical approach is unquestionably the most exact, effective and economical way in engineering problem solving as well as in engineering education. Problem-solving here is defined as a process used to obtain a best answer to an unknown or a decision subject to some constraints [1]. In conventional engineering classes, the students' ability to comprehend engineering principles can successfully be obtained by manually solving a series of multiple engineering problems of progressive difficulty in the same fashion as most engineering textbooks are formatted. The results of this mathematical approach in engineering education seem to be straightforward, maybe even obvious.

However, in this approach, lectures are generally conducted using calculation-intensive platforms and the role of the students in the lecture is relatively limited, and thus they often remain in a passive mode of learning throughout the classes. This factor may result in low levels of motivation, which in turn has caused poor interaction, inadequate understanding and low retention of structural principles. The bitter taste of calculations seems to hinder their active class participation which is an essential step toward conceptual understanding of engineering principles. Thus, the traditional teaching methodology of structural engineering principles seems to need some additional pedagogical consideration to make the students more attracted, motivated and remain focused. To wake up the students out of inactive mode of learning and proceed with the learning process, visual thinking is introduced as a basic catalyst to initial understanding and better retention. While a mathematical approach utilizes formulae and equations to define and clarify the engineering concepts, a visual approach uses graphics and models for communication. The gap between rigidly compliant mathematical thinking and formally flexible visual thinking must be correctly addressed, understood and bridged with carefully devised teaching methodology.

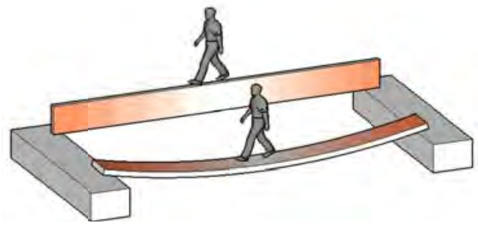
Teaching Methodology

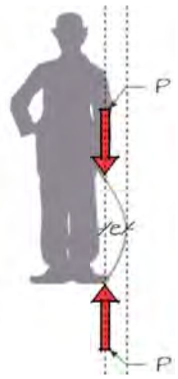
Student engagement is widely regarded as an indicator of successful classroom instruction, and embraces meaningful student involvement throughout the learning environment. It is primarily the teacher's responsibility to initially engage the students, as opposed to the teacher expecting students to come to class naturally and automatically engaged. The challenge remains how to provide engagement opportunities for these students. Students are engaged when they are attracted to their work, persist in despite challenges and obstacles, and take visible delight in accomplishing their work[3]. In a traditional mode of engineering lecture, teachers do most of the talking and students merely passively listen to the lecture. Passive methods of learning, such as listening, do not require students to make neural connections or conceptualization. The conventional class teaching methodology has to be reorganized to provide for sustained engagement between instructors and students. Instructors have to develop systematic strategies that facilitate student engagement in such a way that students can develop behavioral skills and habits that lead to increased academic achievement and greater involvement with classroom activities.

Forming Imagery

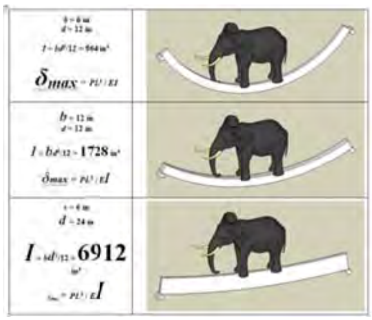
To wake up the students out of the inactive mode in structures courses, it is suggested that bitter taste of mathematics is temporarily reduced to make the students more attracted, motivated and remain focused. When structural concepts are introduced for the first time, the conventional mathematical approach is initially placed on hold. Instead, visible, interactive and even tangible approaches without number-manipulating are opted to be used as eye-opening. More graphics and physical models with less calculation is the key aspect of this paradigm. In other words, visual thinking is emphasized over mathematical thinking and used before the mathematical and symbolic representation of an engineering concept.

The important factor is adding element of playfulness to learning process to help students generate imagery about the new structural concept to be introduced. It is critical in engineering education for students to come up with their own meaning, that is, develop their own conceptualization of what they are learning. For an example, the concepts of moment of inertia can be viewed as a ‘special cross-sectional area’. By following well-designed teaching processes with evolving images, the students could draw qualitative conclusions, and then inferred quantitative relations. Without images or with incorrect images students may have difficulties in forming imagery of their own. The comprehension models are constructed from the more transient mental images that students form and consist of the relevant knowledge already obtained empirically and the new representation needed in problem solving. When the students are successful in constructing appropriate images, they could derive from them the qualitative properties of the situation and the equations that described it quantitatively. If needed, a comprehension model must be appropriately modified to be used to understand of the structural concept and to solve engineering problems. To facilitate imaginary forming, familiar examples can be used to minimize the inactive mode due to seemingly esoteric engineering subjects.

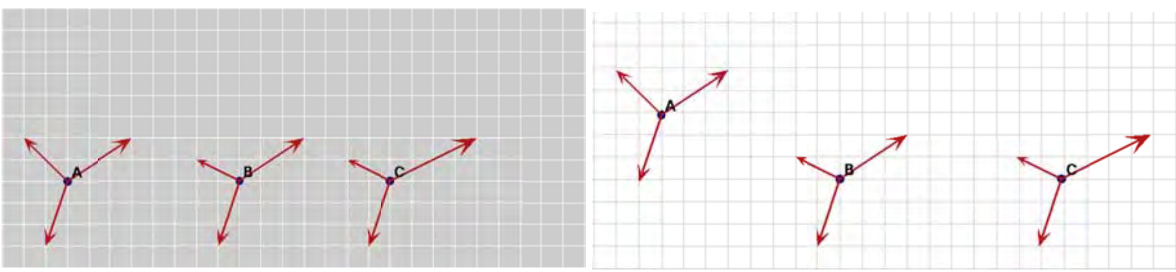




To incorporate active learning in the classroom, it is required for students to take increased responsibility for not only what but also how they learn. Parametric sensitivity test of structural formulae using different font sizes can be a worthy way to let the lifeless symbols and variables in structural formulae talk or express to passive students. This ‘playing with engineering formulae’ exercise provides students with opportunities to get familiar with silent formulae.



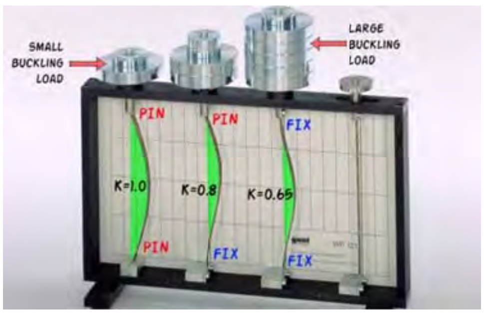
Wherever is appropriate, the structural concepts are explained visually using computer simulation software, 3-dimensional interactive demonstrator and physical models. An educational structural analysis program, called Arcade, developed by the University of Virginia has been extensively used in my structures classes to encourage students to engage with and conceive an idea (or imagery) of the structural concept through observation and imagination.

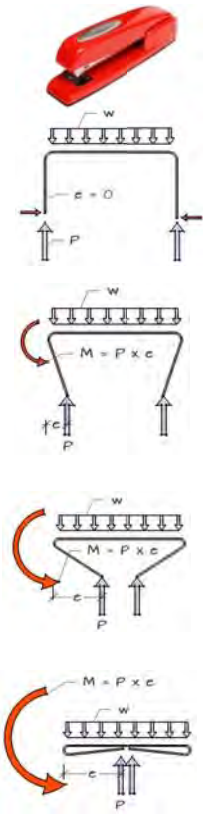


Effects of horizontal and vertical components and concepts of equilibrium are acquired by simply counting the number of grids in the x- and y- directions instead of using trigonometry.

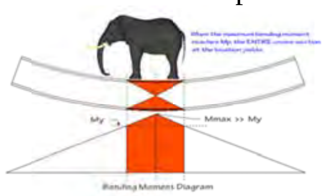
This free software takes a different approach to the user interface and to the underlying theory to create a new kind of structural analysis program which enables new modes of teaching with analysis software. Because the analysis and interpretation stages are merged so that the program is capable of interacting with a model while an analysis is in progress. This means that the analysis model can be changed and then the user see the effects instantly, the way that a game player sees a game respond to input. This game-like software is capable of not only simulating structural behaviors as simple as the effect of a force system acting on a particle but also modeling non-linear large-displacement phenomena such as the changing shape of a hanging cable, or the buckling of a frame[3].

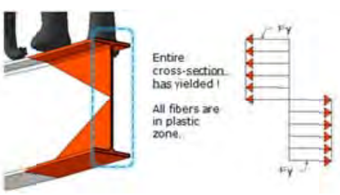
Mathematical Approaches with Visual Thinking





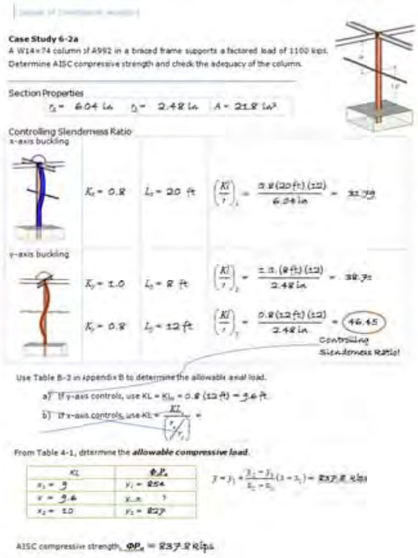
In engineering education, it must be noted that school math was about doing while college math is largely about thinking. Mathematical understanding is to develop the thinking skills that will allow students to solve practical, real-world problems for which students don't know a standard procedure. (In some cases, there may not be a standard procedure). However, mathematical approaches often override students' reasoning processes. It has been noticed in engineering classes that mathematical skills and competencies are often themselves the center, and sometimes the whole, of instruction. Students in engineering classes seem to pay more attention to problem solving technique without being attentive to the underlying concepts. Most of structural engineering textbooks and traditional teaching methodology may have been pushing students toward problem-solving more than toward conceptual understanding. When structural principles are reduced to a series of calculation without apparent link to structural forms, they become miserably boring engineering subjects to students. If there is no bridge between informal meaning making and formal mathematical reasoning, the two often remain disconnected.

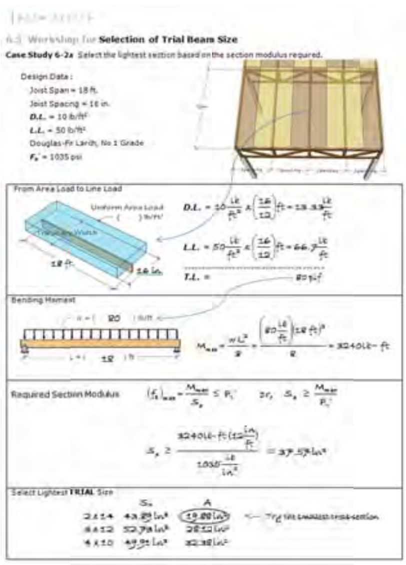




A selected set of structural engineering problems with progressive difficulties are utilized as lab exercises. These are almost the same as ordinary civil engineering classes except that the visual and qualitative understanding formed are linked to the problem solving in pre-formatted case studies and workshop problems. The same visual elements used for observations and experiences in the introductory phase are inserted in the templates. Approaching an engineering problem by using a proper template is still useful in the first stage of many parts of college engineering education.

Use of Structural Worksheet with Visual Understanding

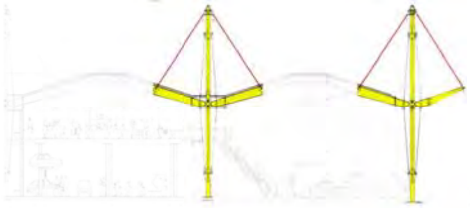




Load Path **shown by directional arrows on an actual structure**

In order to understand physical phenomenon conceptually, students need to read it with comprehension, to modify or build concepts, and to understand the governing equations. This involves building comprehension model, and doing qualitative and quantitative reasoning. Mathematically testing a comprehension model is not only the most effective and economical way in this stage. This phase is referred to as convergent thinking which follows a particular set of logical steps to arrive at one solution, which in some cases is a "correct" solution. However, approaching a new problem by looking for a template to follow, a formula to plug some numbers into, or a procedure to apply at times won’t work. What would you do in the situations? The answer, and this is the second key step, is to think through, evaluate options, and create a new visual imagery. This step requires making a lot of mathematical exercises about structural principles until they become second nature. There seems to be no royal road in this process of learning. No pain, no gain. Once students get used to it, they will gain an intuition for it and will start seeing things visually with a fuller understanding and mastery of structural principles. While several variations of a structural formula are utilized are provided for wider adaptability, multiple different exercises using the same formula are also necessary for deeper confidence and longer retention in this stage. The main drawback to this traditional mathematical approach is their abstract nature. Problems from the back of a textbook chapter tend to narrowly focus on only one specific aspect of structural calculations at a time. Finding reactions on beams, constructing shear and moment diagrams, or analyzing trusses are certainly useful skills. However, these types of problems are too often performed on isolated elements devoid of any structural context. It is critical at this phase of learning to make abstract concepts visible and connect them with concrete examples. Real-world structural design problem-solving has proven to be a successful way to actively engage students in the reflective learning environment. Structural design exercises are a dynamic, interactive way to teach structures as design. This style of assignment offers several advantages over traditional problem sets, which are often completed individually. By refocusing structures courses on form finding and only using specific structural calculations to check and confirm schematic designs, students realize the role that calculations play in the overall structural design process. As a supplemental learning exercise, the following elements can be utilized:

1. Study of rationale behind structures that are found from nature and explicitly used in famous architecture constructs the links that connect visual thinking to structural calculations.



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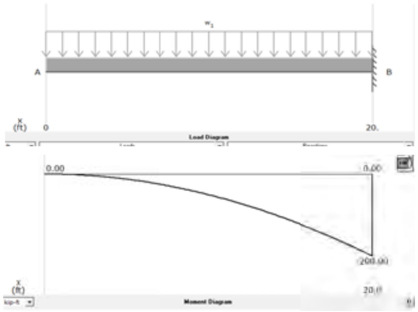
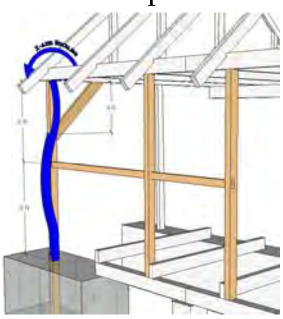
2. Connecting bending moment diagrams with architectural shapes

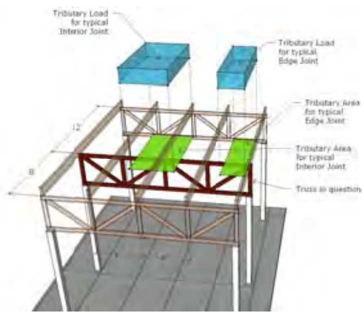


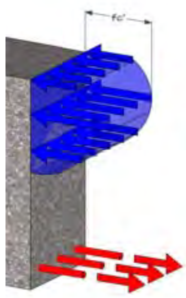
The bending moment diagram of a cantilever subjected to a uniformly distributed load.

A high-riser can be viewed as a cantilever sticking out of the ground and subjected to lateral loads.

3. Interactive 3-D demonstrators are indispensible teaching tools for visual understanding of the structural concepts.



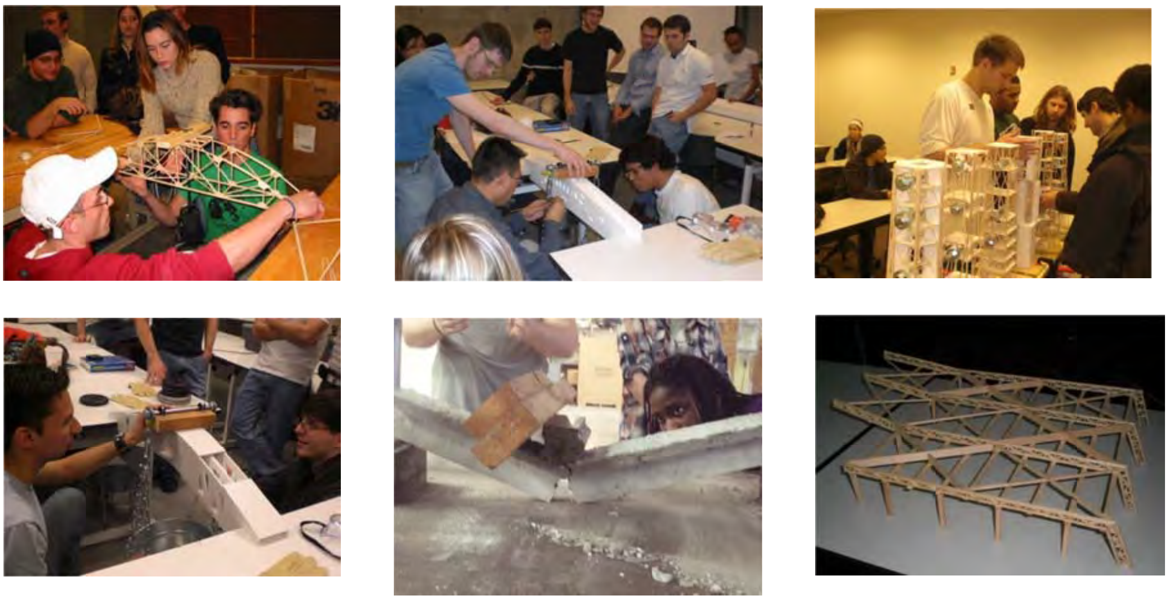




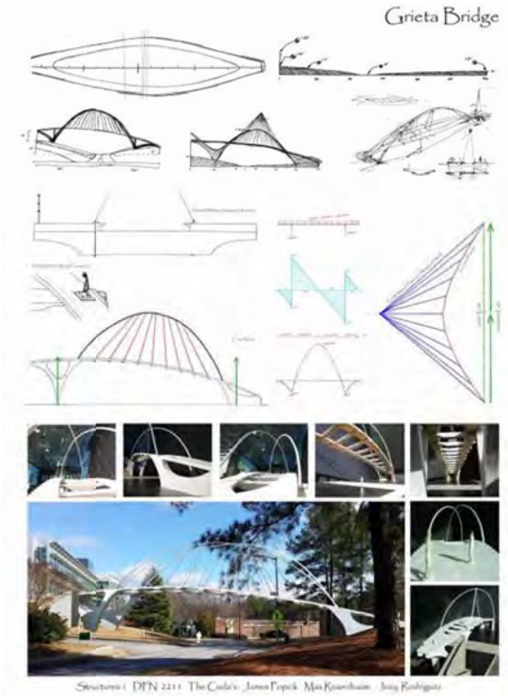
4. Paring difficult quantitative problems with simple qualitative questions.

Application and Integration

Learning through experimentation and fabrication has been demonstrated over the years as an effective method in the communication of structural ideas. To verify and fortify the structural knowledge acquired through graphics and calculations, students are to work with physical objects in a small group environment. Small-scale models, commercial construction toys, and structural term projects are utilized in this stage. Students are to understand and appreciate the real 3-dimensional structural behaviors during their designing, building and testing of their models. These empirical understanding provides the students with ample opportunities to verify and fortify their idea on structural forms. Moreover, the 3-dimensional structural behaviors often reveal the limited scope of the class and allow the students to realize the gap between the textbook solutions, which are generally in 2-dimensional planes, and the real-world physical phenomenon. Brief qualitative solutions are given by the instructor about the potential deviation to quench possible curiosity. The collaborative learning group is apparently a successful way of active learning because it causes the students to review the work that is being required at an earlier time to participate. The students can enhance their conceptual understanding of structural behavior by seeing the application of the abstract ideas presented during classes and are excited by competing spirit of the testing project models. At the end of each project, students are required to provide project presentation about how they chose and developed their initial ideas and the reasoning of their decision makings. I found this required more student accountability and involvement than the passive lecture environment. By comparison, in the lecture portion of the course students are less interested in exploring their own curiosities about the subject material. Also, I make students grade the other teams' performance in the project. This stimulates students' intrinsic motivation to work on the project and think deeply about the subject.



Small-scale modeling, balsa wood truss contests and plate girder contests were found to be the most challenging and yet enjoyable. These components have received the strongest supports from the students in the evaluations and surveys. The experimental performance data and team presentation material have been documented every semester for future references.



Synergetic relationships between mathematical and visual approaches can be clearly utilized in teaching truss analyses – The method of joints with accurate numbers and Maxwell diagrams of scaled truss forces provides advantage of visual feedback and their respective senses (compressive/tensile). For an example, Maxwell diagrams better provide students with more conceptual understanding when the effects of the depth of a truss on the internal member forces.

Conclusion

The use of dynamic simulation can be used as a very effective tool to provide engineering student with visual understanding to inspire conceptual understanding of elementary statics. Although this educational exercise could be contrary to popular belief that engineering students should begin with linear elastic static analysis, and then progressively work toward non-linear dynamic analysis. The possible reasoning behind this is the fact that non-linear dynamic analysis is much more complex to perform but can be more visually understood with less efforts. Playing with engineering concepts as a first step of class without the bitter taste of mathematics more easily engages the students in the subject concepts. Visual approaches can be successfully designed into structural engineering classes to provide initial understanding and better retention of the meaning of the numbers used in mathematical approach. The balance between visual and mathematical understanding in structure classes must be properly addressed and maintained since they complement each other. Visualizing and experiencing 3-D structural behaviors help students realize the deviation between the textbook solutions and the real-world physical phenomena. Small-scale modeling provides students with opportunities to find that learning structures could be an enjoyable experience that leaves a stronger impression for longer retention. Studying historic and modern buildings which have distinctive structural elements as structural forms strongly connects them to the technological side of buildings.

References

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