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A Theoretical Basis for In-Class Demonstrations

Prof. Eric Bell, Triton College, Ret.

A graduate and postgraduate of University of Illinois at Chicago, formerly a professor at Triton College in engineering and computer science, now retired. Postgraduate studies in education also at University of Illinois at Chicago.

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Abstract

A session of the ASEE Mechanics Division which has drawn considerable interest in recent years is the demonstration session. In it, participants describe presentation tools and activities that have been used during classroom lectures. Their observations have led them to conclude that the use of relatively simple and/or inexpensive demonstrations result in a more effective learning experience. Most engineering professors have not deeply studied educational psychology, and so may not be fully aware of the background of their activities and their implications in the learning process. As a result, while their demonstrations may well be effective teaching and learning tools, with deeper understanding they may be able to design and implement classroom and lab demonstrations with still greater impact on their students. This paper will discuss theories of scientific understanding and cognitive dissonance as they apply to an engineering classroom, results of which can be used to design effective classroom and lab demonstrations. Definitions and examples of scientific learning and cognitive dissonance will be discussed.

Introduction

The structure of scientific understanding has been well described by Kuhn[1], a physicist turned philosopher. His description of scientific understanding is that understanding and description expand until there are too many outlying data to reasonable ignore, and a new model and subsequent description is required and instituted. Here, "description" is used as a label for equations and processes that are used to describe properties and behaviors exhibited by and within mechanical systems. As engineers, we see this regularly because we are exposed to new or emerging technologies and processes. The word "expansion" will be used to mean the addition of mathematical terms or processes to an already existing description. A useful example of expansion is the Bernoulli equation. At its heart, the Bernoulli equation is an energy equation. The original equation defined by Bernoulli is only slightly different from the equation we use today. (My undergraduate fluids professor referred to it as the Modified Bernoulli Equation. He made quite a to-do in class about the use of the word "Modified." To quote him, if it was "the *Modified* Bernoulli Equation, then is was no longer the Bernoulli Equation.") Learning in a scientific manner is commonly represented as extensions of already understood knowledge.

An example of radical change occurred in the 16th century when Galileo worked to consolidate the understanding of solid mechanics[2]. In one case prior to his involvement there was more than a little controversy about whether the bending stresses of cantilevered beams caused tension at the top of the beam, or compression at the bottom as illustrated in Figure 1. It was during this time that the two concepts were consolidated and explained. In this way, two previously disparate explanations for observed forces or loadings were replaced by a single unifying explanation which we still use today.

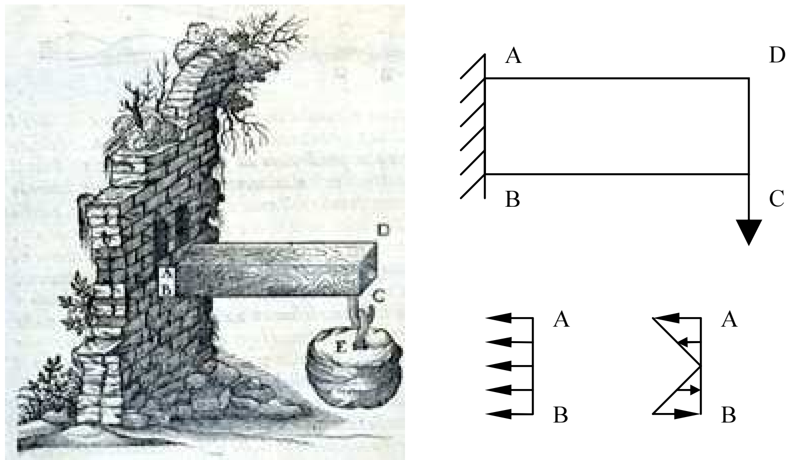

Figure 1. (Timoshenko, 1953)

A still more radical change in scientific understanding can be seen in the difference between momentum and energy equations. Prior to Newton's *Principia* and his description of energy, understanding of bodies in motion was limited to "impetus" and momentum. Both are conserved and are useful, but they are used in difference circumstances. The expansion of the concept of momentum into energy allowed for more interesting and complete descriptions of mechanical events and behavior.

Cognitive dissonance is commonly understood to be holding two ideas or concepts that are contrary to each other[3]. While this is true, another valid description is that an experience is new and, hence, not known to the observer. If we examine the phrase, we see that the first word is "cognitive." This means that this is something that a person is thinking about, either consciously, or unconsciously. In either case it is an activity of the mind.

"Dissonance", suggests difference or disagreement. While in its most extreme conditions dissonance can describe a contrary condition, it doesn't have to be that extreme. In fact, in its less intense state, dissonance can be described as that which is not accepted or integrated into the existing framework or model. When it initially occurs, dissonance is often attention-getting because an observation does not fit into a preexisting understanding or knowledge of the environment. As an example, advertisers use this model to great effect, changing promotions, billboards, commercials on a regular basis. This is in an attempt to get your attention and hopefully convince you to buy their product or service.

In an academic environment cognitive dissonance can be used as an opportunity for learning[4]. Dissonance has been described as arousal, and thus has the limitation of an emotion in that it can have both intensity as well as duration. The opportunity can pass or expire and there is no guarantee that the learned capability will be valid. Since teaching is a structured environment including activities for learning, it is a situation of which can be taken advantage of by the professor[5].

The use of fabricated situations stimulating or provoking cognitive dissonance used to increase learning has been studied before[6]. Since the topic of this paper is primarily focused on classroom or lab demonstrations, it is presumed that the generation of dissonance is similarly staged. That is, the professor is intentionally creating a observable event that generates cognitive dissonance within the student, and thus a learning opportunity.

Classroom or lab demonstrations commonly have either no expectations, or extreme expectations. By "no expectations", it is meant that the students do not expect to see anything new or unusual. "Extreme expectations", means that there will be some observable event, but it is completely preordained in the student's mind. A common thread between the two is that there will be no *unexpected* behavior or action. To modify a contemporary phrase: "nothing new to see here."

If there are no expectations prior to the demonstration then the observer is left with wonder at what just happened and how to describe or explain the event. This would be the case in an initial exposure to an observable phenomenon. Such would be case with natural phenomena.

An Example in Natural Science

Giraffes have been known to Europeans since before Roman times, but like so any things, begged to be rediscovered. About the time of the Renaissance, European explorers came across giraffes and, not having photography, attempted to describe them. Initial descriptions were of creatures, horse-like in structure, but with very long legs and necks. This is obviously not a completely adequate description, so artists produced drawings. Interestingly, drawings of giraffes at the time were unusually short-necked. A contemporary viewer of the artwork would describe them as giraffe-*like*, but with necks that are too short. It was a belief at the time that sponsors and peers would not believe that an animal with such an extraordinarily long neck could actually exist. It was not until later expeditions were more forthcoming that the true nature of giraffe neck length became known and accepted.

Cases such as the re-discovery of the giraffe are themselves examples of the first step in scientific explanation - identifying it and naming it. It has been the nature of early investigation to merely see what is there, and then attempt to describe it.

Scientific understanding allows for expansion of descriptors once this first step is accomplished. In the case of giraffes, there are now known to be nine different sub-species. Each sub-species has their own particular markings [Figure 2] and range [Figure 3] within the African continent.

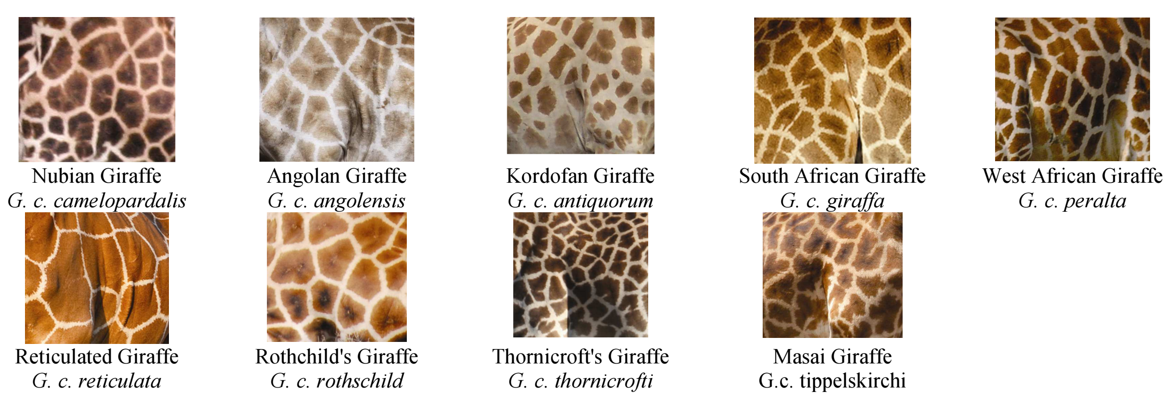

Figure 2. Giraffe markings.

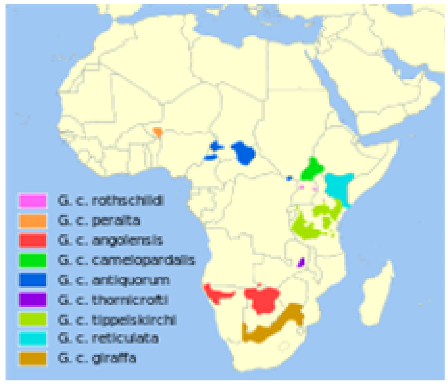

Figure 3. Giraffe ranges.

In the case of the rediscovery and subsequent study of giraffes, the initial response to the giraffe was wonder at how such a creature could exist because it was so different from known or previously observed animals. Thus, it generated cognitive dissonance for the explorers. It would appear that describing it as horse-like was an attempt to relate it to an already known genus though that was later discarded. Later study identified and described features of each sub-species, such as the markings and continental range identified here, illustrating the implementation of scientific understanding. Here is a case where both cognitive dissonance and expansion of scientific understanding are applied.

Example Classroom Demonstrations

A classroom demonstration that has been presented in the division's previous demo sessions employs several cylinders of equal mass and appearance. The demonstration is marked by the following:

- cylinders are shaped the same
- cylinders weigh the same

Given these simple conditions there is a naïve expectation by students that they should behave the same but the naïve expectations of students can be difficult to establish. By their very nature, classroom demonstrations are the equivalent of a loaded question - student may well be aware that something unusual is going to happen if the professor is expending so much class time and effort into an activity.

The professor or students roll the cylinders down an incline and are either timed, or in parallel as in a race. Students are prompted by the professor to acknowledge variations in performance between the cylinders. If dissonance is present as expected then there should be an emotional response marking a cognitive state ready to resolve the dissonance.

There are multiple activities that follow engaging the professor and students, but all result in the expansion of energy equations with regard to rotational dynamics. The new capability is derived from a previously known structure, i.e. $\frac{1}{2}mv^2$ can be used to derive $\frac{1}{2}I\omega^2$.

There is no reason that cognitive dissonance demonstrations should be limited to physical demonstrations or even mechanics. I have taught an introductory computer programming course. In an early programming exercise students had to convert degrees Celsius to degrees Fahrenheit. As part of the exercise I wrote at the instructor's station which used a projector, and they copied onto their workstations, a program that converted user input Celsius to Fahrenheit. The expression used to convert Celsius to Fahrenheit is shown in [1]. As part of the exercise, we then modified the program to convert degrees Fahrenheit to degrees Celsius using the code modification steps shown below:

```
[1]     degF = degC / 1.8 + 32
[1']    degC / 1.8 + 32 = degF
[2]     degC / 1.8 = degF - 32
[3]     degC = degF - 32 * 1.8
```

After making the above changes, I ran the program and entered an obvious value for degrees Fahrenheit, "32." The result should be the obvious solution of "0." But when run, everyone - including me - was presented with an incorrect solution. I expressed surprise.

"Whoops! What's this? We got the wrong answer!"

In an instant 30-odd faces popped up from behind their computer screens. This was clearly not expected and was attention getting, with a strong sense of arousal. Anyone who has spent much time programming will see the error. The final line of code should look more like [3'].

```
[3']    degC = ( degF - 32 ) * 1.8
```

I had their attention, so I took this opportunity to explain operator precedence and its implications in calculation. A dry explanation of operator precedence without the "trauma" would likely have been ignored or glossed over by the students. As it was, they saw that this property of programming languages has a real impact on their results.

Discussion

It could be argued that scientific understanding and cognitive dissonance occur at both the individual and institutional level. While Kuhn was primarily referring to the institutional or cultural level for expansion and restructuring of scientific knowledge, his arguments apply well at the individual level, which is where we dwell. In fact, most engineering education attempts to expand the student's understanding of a subject, segueing from one state of understanding to another rather than dismissing past understanding and starting anew. As an example, the transition from momentum to energy methods is one of the few times that this is done. The use of momentum is augmented by energy methods, but even then momentum is not dismissed, but relegated to special cases.

The expansion of scientific understanding requires detailed investigation. In many cases events surrounding identified objects are not identical. Details previously missed or simply not recognized may be useful in generating more complete descriptions. In the case of giraffes, detailed study by explorers and zoologists identified several sub-species of giraffes and their ranges. In the case of the rolling cylinders, the concept of moment of inertia must be described and explained. This kind of explanation leads to a new property requiring integration into the already known set of descriptors. With this, the student's scientific understanding may expand more readily in a new and interesting way. The experience of observing the cylinders and then learning how their new understanding is integrated into existing knowledge, students can continue a process of associating descriptors with behavior. That is,

- properties/descriptors describe to behavior/observations, and
- behavior/observations imply properties/descriptors.

In this way, it becomes apparent that scientifically learned properties and behaviors are inversive, which is to say that properties of a mechanical system control behavior and its characteristics, and that an observed behavior on the part of a mechanical system suggest its mechanical properties. An example if this is the observed downward force caused by an object relating to its determined mass. Conversely, knowing the mass of an object will predict its downward force.

In the case of giraffes, if you see a giraffe with particular markings or pattern, you can be pretty sure of original range. Similarly, if you observe two rolling cylinders accelerating at different rates, and their outside appearances are equivalent, then you can be pretty sure that another property related to moment of inertia is responsible.

How does this effect the design of classroom demonstrations? The appropriate timing of demonstrations is important. As described cognitive dissonance has an emotional component and thus has a limited time for exploitation. If at all possible the demonstration should exhibit only one type of new behavior, so as to not confound the student with more than one new behavior and therefore more than one new or overly complex descriptions. An example of this has been seen in the rolling cylinders demo where cylinders tended to exhibit sliding in addition to rolling. The curriculum was not ready to include the description of sliding at this point and the presence of rolling did not aid in validating the description using pure rolling. Modification of the cylinders and the rolling surface to preclude sliding would be helpful.

Conclusion

In most cases, classroom and lab demonstrations require preparation and rehearsal. In this way, the professor knows which behaviors will be exhibited and how to segue into describing them. If at all possible, the demonstration should exhibit only one new behavior. In the case of the rolling cylinders, later demonstrations using the same setup could include sliding, comparing pure rolling with a combination of rolling and sliding.

Scientific learning is used to expand understanding in mechanics. Observations of behavior are used to create new descriptions which account for that behavior. Classroom demonstrations should be used to present mechanical behavior that is new to the student in a limited or constrained manner in order to minimize extraneous behavior such as unwanted sliding.

The presence of cognitive dissonance is used to generate the disconnect between the already known with the observed. Given the emotional basis for dissonance there is a limited time in which to resolve it. It would be suggested to resolve the dissonance within the same class period.

If the professor should go in the direction of new discovery, smaller groups could be presented with the behavior, and then left with tools to examine the components. This would allow the students to make the observations themselves, and then derive expressions for expansion of the descriptions. The limitation of this approach is that it could require much more time and resources than is readily available, but could be extremely effective as a form of realized mechanics.

Its been said that there are few things as useful as a good theory. The theory of scientific learning provides a framework for expanding an existing knowledge-base that makes it easier to learn and subsequently understand science-based domains. Cognitive dissonance is known to generate student arousal or attention, initiating an emotional state and subsequent cognitive process so that learning may more readily occur. Using it as a demonstration design goal can help prime the intellectual pump, preparing the student for effective learning. With the consideration of these theories, demonstrations can be designed and used in the classroom to teach with greater effect than lecture alone.

References

1. Kuhn, T., (1962). *The Structure of Scientific Revolutions*. University of Chicago Press.
2. Timoshenko, S., (1953). *History of Strength of Materials*. McGraw-Hill, New York, N.Y.
3. Festinger, L. (1957). *A Theory of Cognitive Dissonance*. Stanford University Press, California.
4. Aronson, E., (1995). *The Social Animal.* W. H. Freeman and Co., New York.
5. Guzzetti, B. J.; Snyder, T. E.; Glass, G. V.; Gamas, W.S. (1993). "Promoting Conceptual Change in Science: A Conceptual Meta-Analysis of Instructional Intervention From Reading Education and Science Education". *Reading Research Quarterly,* **28**: 116-159.
6. Graesser, A. C., Baggett, W., & Williams, K. (1996). "Question-driven Explanatory Reasoning". *Applied Cognitive Psychology*, 10:S17-S32.
7. Losch, M. E., Cacioppo J. T. (1990). "Cognitive Dissonance May Enhance Sympathetic Tonus, But Attitudes are Changed to Reduce Negative Affect Rather than Arousal". *Journal of Social Psychology*, 26: 289-304.
8. Cooper, J., Zanna, M. P., Taves, P. (1978). "Arousal as a Necessary Condition for Attitude Change Following Induced Compliance". *Journal of Experimental Social Psychology*, 10:1101-1106.
9. Cooper, J., (2007). *Cognitive Dissonance: Fifty Years of a Classic Theory.* SAGE Publishing, California.