# AC 2011-969: THE EFFECTS OF ENGINEERING DEMONSTRATION DESIGN ON LEARNING AND INTEREST

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# The Effects of Engineering Demonstration Design on Learning and Interest

## Introduction

It is widely recognized that class room demonstrations increase the interest and motivation of students to learn new concepts in comparison with the standard "chalk and talk" lecture environment[1-3]. In his work on engineering pedagogy, Felder emphasizes the need for frequent use of demonstrations in order to balance concrete and abstract information in engineering courses, thereby appealing to the greatest number of student learning styles[8,9]. Lowman's 2-dimensional model for effective teaching also supports the use of class demonstrations as a means to improve teaching by raising the intellectual excitement in lecture and potentially improving interpersonal rapport between students and teachers[10]. Active learning proponents advocate the use of in class demonstrations as well, and have shown that they may be used at all stages of the learning process to motivate engineering topics, create connections between math models and physical behavior, and to reinforce analytical developments after a lesson has been completed[11]. Campbell reports that in the case where students are taught using lecture and demonstration, information retention rates rise from 20% to 50% compared to the conventional lecture environment[12]. This rate rises to 70% retention if demonstrations are designed to incorporate student interaction. Examination of the literature shows numerous studies which document the benefits that particular demonstrations have had in helping students master concepts in technical fields such as physics and engineering [4-7]. A particularly interesting attempt to provide wide scale distribution of thoroughly tested engineering demonstrations was undertaken by engineering faculty at the United States Military Academy in collaboration with McGraw-Hill publishing[13]. An online data base, (www.handsonmechanics.com), was developed featuring over 30 demonstrations, each of which were simple to implement, relatively cheap, and proven effective in the classroom environment.

While the literature is replete with case studies, as well as theoretical justification for the use of demonstrations in teaching, the emphasis of the research is primarily on the functions performed by the demonstration. Currently there is little work available that characterizes the physical features of demonstrations, (i.e. the look and feel of demonstrations), that make them effective teaching tools. Consider for example two demonstrations that are functionally equivalent but in one case the demonstration consists of a highly stylized piece of equipment purchased from a specialty manufacturer, while in the other case the demonstration is cobbled together from spare parts without any concern for aesthetics. Given the difference in construction quality for the two demonstrations, is there any pedagogical advantage associated with the professionally manufactured demonstration equipment versus the home built demonstration ? Anecdotally there is much evidence to suggest that engineering students prefer less stylized, "raw", demonstrations, as opposed to professionally packaged demonstration equipment. In this work, a systematic examination of the effect of demonstration finish quality on learning efficiency is described.

In particular, demonstrations with a high degree of finish, or “polished” demonstrations are compared with “raw” demonstration equipment for a population of students that consist of both technical and non-technical majors. Two case studies are considered; one in which a model monster truck is used to motivate lectures on spring/mass/damper systems, and the other where a laser based communications system is used to explain electronics concepts. For each case, students are divided into two groups corresponding to raw and polished demos respectively. Following a brief in class lecture, each group of students is then given a quiz to measure the effect of the various demonstration styles on learning. Results for objective comprehension, as well as self assessed learning and enjoyment are presented for each case study and the effect of demo construction quality on these learning metrics is discussed.

Case I: Monster Truck Demo

In first case study, a radio controlled monster truck model was used to demonstrate mechanical vibration concepts via its suspension system for a lesson on spring/mass/damper systems. For the purposes of examining the effect of a polished demonstration, the body shell of the monster truck was left in place, hiding much of the frame and power train, but still leaving the springs and shock absorbers of the suspension visible, (Figure 1). The “raw” version of the demo consisted of the monster truck with the body shell removed, making it possible to see the suspension components and the rest of the internal structure of the monster truck model, (Figure 2). A total of 119 students were involved in the study; 62 technical majors such as Engineering and Physics and 57 students from nontechnical majors such as History and Psychology. Students were divided into two groups, one of which received a lecture on spring mass damper systems with the polished demonstration, (i.e. the monster truck with body shell), and the other group receiving the lesson with the raw demonstration, (i.e. monster truck without the body shell).


Figure 1: Polished Demo for Spring/Mass/Damper Lesson

Figure 2: Raw Demo for Spring/Mass/Damper Lesson

The specific break down of majors for each type of demonstration is given as follows:

| Raw Demo | Polished Demo |
|---|---|
| 30 students technical majors | 32 students technical majors |
| 32 students non-technical majors | 24 non-technical majors |

During each of the lecture sections, the suspension system of the monster truck was used to introduce concepts such as:

- Spring stiffness: relation between the deflection of a spring and the restoring force on the spring
- Dampers: relation between damping force and suspension motion
- Sprung Mass
- “Soft” and “Stiff” suspensions and their relation to vibration characteristics

Students were encouraged to examine monster truck, and move the various suspension components as the lecture progressed.

Following the lecture, each group of students was given a five to ten minute long quiz consisting of 10 questions, (see Appendix I). Three types of questions were included on the quiz, in order to assess students Objective and Subjective comprehension of the material, as well as their self-assessed enjoyment/interest in the material:

- **Objective Comprehension**: The quiz included 7 questions aimed at assessing how well students learned concepts from the lecture concerning spring mass damper systems. For example:

"7. A new car design tends to ride too "rough", meaning on bad roads the passenger cab vibrates too much. What parts might need to be redesigned to fix this?

a) The dampers and the springs. They are interrelated.
b) Only the dampers. The springs do not affect ride roughness.
c) Only the springs. The dampers do not affect ride roughness."

- **Subjective Comprehension**: The quiz included one question in which the students provided their own assessment of how useful they felt that the demonstration was towards helping them learn the material presented in the lecture:

"3. How did the demonstration help you understand the subject matter?

a) Having a chance to examine the demonstration clarified some things that I would probably not have understood from the lecture alone.
b) Having a chance to examine the demonstration showed me that I correctly understood the material about springs and dampers taught in class but didn't help me learn anything new.
c) The demo might be cool looking, but it didn't really help me understand anything about suspension systems.
d) honestly didn't bother to look at it much"

- **Subjective Enjoyment**: The quiz included one question to assess how students' interest in the subject area changed as a result of seeing the demonstration.

"2. How did the demonstration of the model car affect your interest in the subject matter

a) The demo made me much more interested in the lecture material; I'm likely to find out more about suspension systems on my own time because of it.
b) I found seeing the demo made me more interested in hearing the talk about suspension systems. Still, I doubt I'll be Googling to learn more about suspensions systems in the near future.
c) The demo was interesting in itself but didn't make me want to learn about suspension systems, either in the talk or outside of class.
d) The demo was lame and reinforced my opinion that I just wasted 10 minutes of my time."

For subjective enjoyment and subjective learning, responses a, b, c, d, were scored as 3, 2, 1 and 0 respectively. The results for each quiz were normalized on a 0-1 range, and the average scores for objective comprehension, subjective comprehension and enjoyment plotted in figure 3 with error bars corresponding to the standard error of the mean.

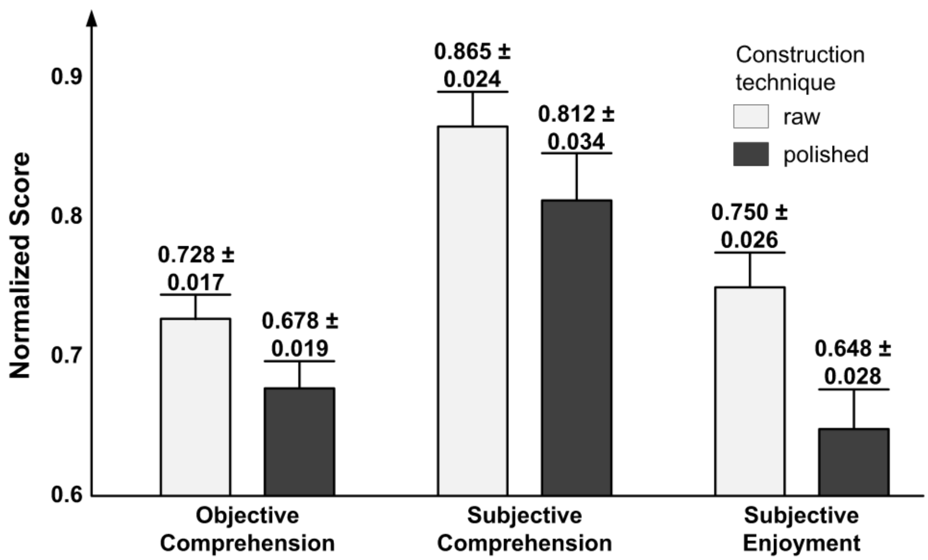



Figure 3: Student Results for Raw and Polished Demonstrations

Based on this graph alone it appears that the raw demo for the monster truck tutorial was more effective than the polished demonstration. Two tailed T-tests were also applied to the data to evaluate whether the apparent difference in the mean test scores for the raw and polished demos were statistically significant. For objective comprehension, a p value of .053 was obtained for the two-tailed T-test, while a p value $< .01$ was obtained for subjective enjoyment. Both of these results indicate that the method of construction for a demonstration has a statistically significant impact on learning. In the case of subjective comprehension, the T-test resulted in a $p>.2$ showing that there is no statistically significant difference between the students' perceptions of the usefulness of a demonstration regardless of its construction quality.

Results grouped by major revealed grossly similar findings. Grouping did not alter trends, although smaller experimental sub-groupings removed statistical significance from all measurements except non-technical majors ratings of enjoyment (Figure 4). These showed they overwhelmingly preferred the "raw" demonstration quality ($p<0.01$).

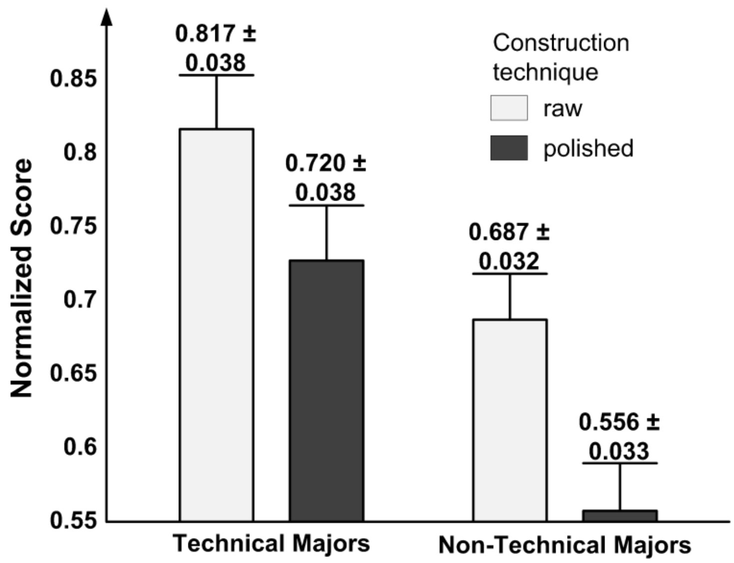



Figure 4: Subjective Enjoyment Scores By Student Major

**Case II: Laser Communicator:**

In the second case study, electronics and signal processing concepts are demonstrated using a communication system that transmits a voice signal over a laser beam. The system consists of a transmitter which converts sound waves into an amplitude modulated laser beam. The beam is then converted back into sound waves by a receiver located 10 – 20 feet away from the transmitter. As shown in figure 5 the receiver consists of transducer stage, (reverse biased photo-diode), a high pass filter stage, and then finally a power amplification stage. Concepts that can be illustrated using this relatively simple circuit include:

- Sensors
- Design of filters using resistors and capacitors
- Practical power amplifiers

In this study a "raw" version of the receiver system is built up using discrete components on a bread board as shown in figure 6. A polished version of the receiver was fabricated using a rapid prototyping machine to create a sculpted enclosure for the receiver which included a rotating mount and a parabolic reflector for alignment of the laser beam to photodiode element, (see Figure 7).

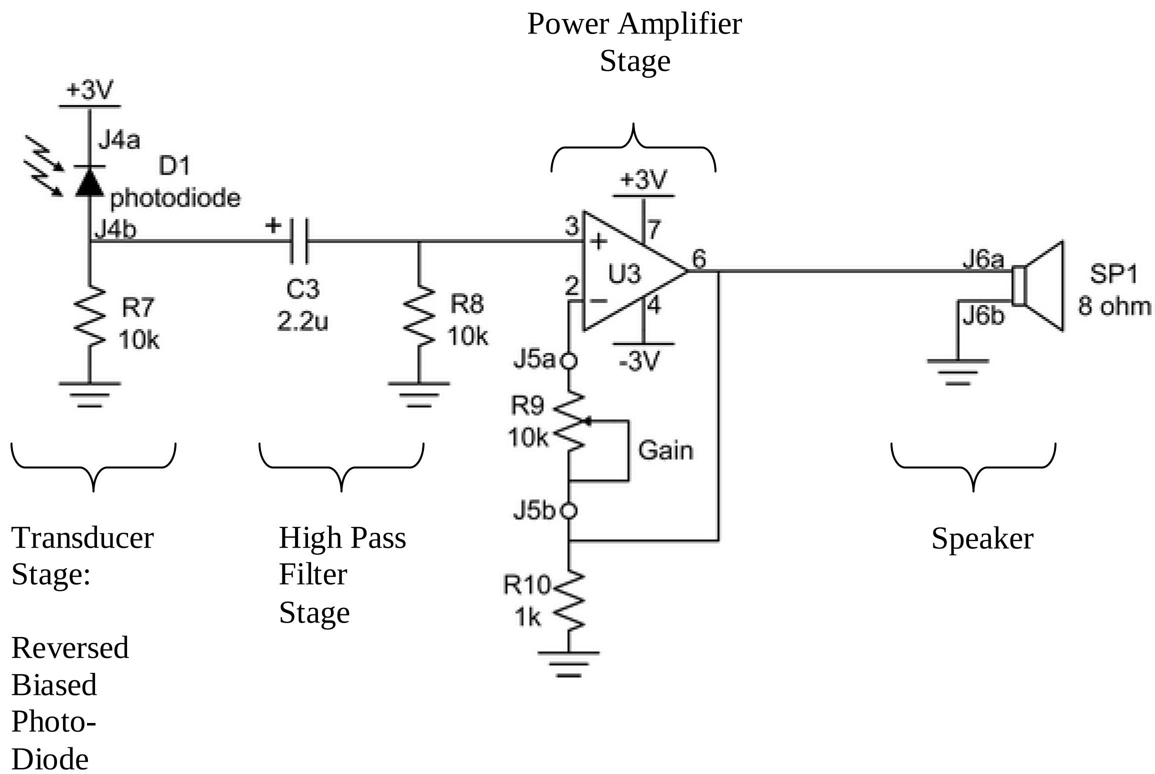



Figure 5: Schematic of  Receiver for Laser Communicator System

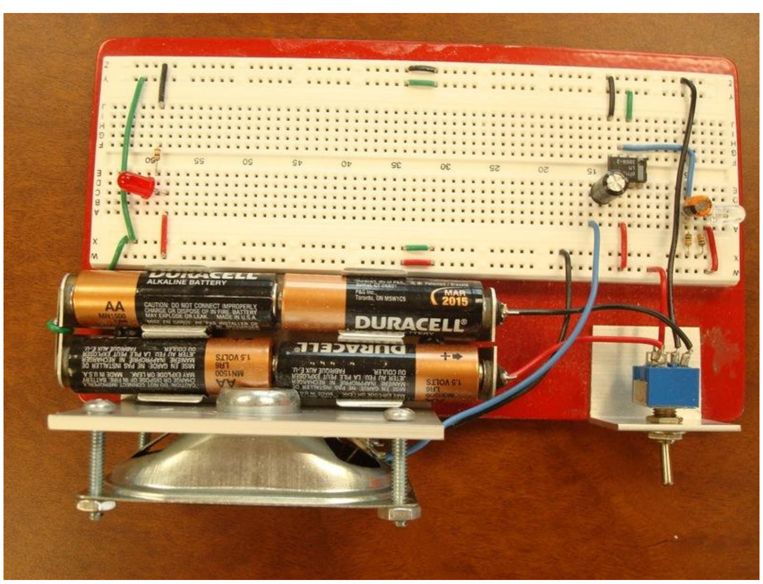
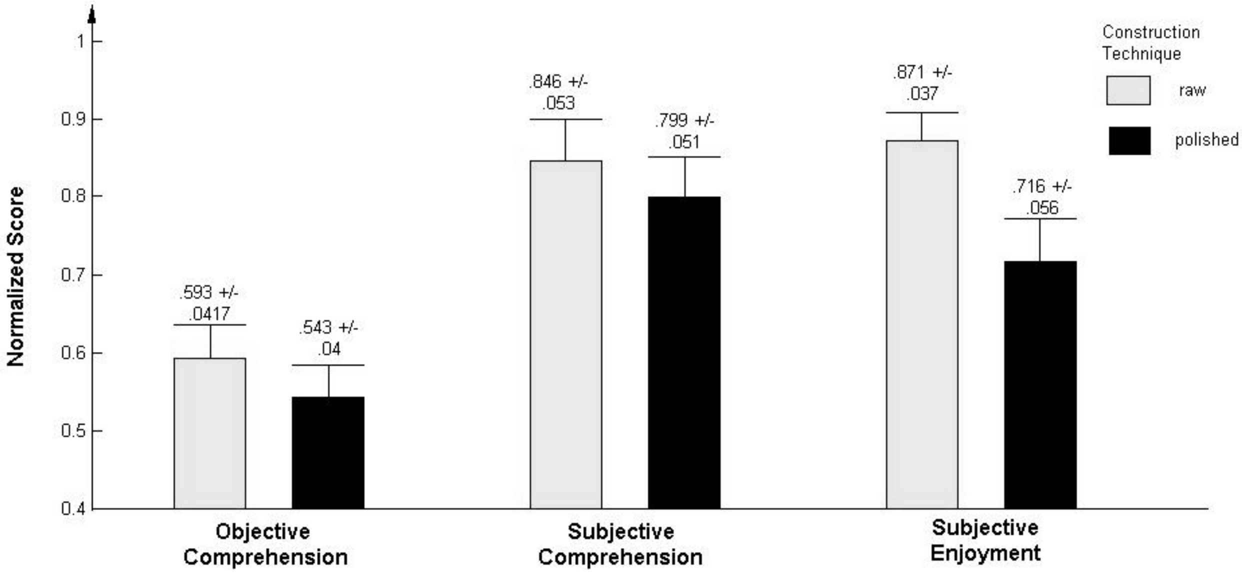



Figure 6: Raw Version of Receiver Demonstration

Figure 7: Polished Version of Receiver Demonstration

A total of 46 mechanical engineering students were involved in the study, with 26 students taking part in a lecture with the "raw" bread board based demonstration and 20 students using the polished demonstration. Each group of students was given a brief lecture explaining the concepts behind the operation of the receiver, after which a quiz was administered to assess objective learning, subjective learning and subjective enjoyment, (see appendix II). Prior to the lecture portion of the lesson, students were encouraged to use the demo to transmit messages in the classroom. Although no electrical circuit adjustments could be made, the students did get a chance to investigate the effects of beam alignment on the clarity of the messages received.

Results for the receiver case study are plotted in figure 8, and show that in general objective learning scores were noticeably lower than for the monster truck study with average scores for the raw and polished cases reaching only .593 and .543 respectively.




While the raw demo for the receiver does result in higher mean objective comprehension scores than for the polished demo, a two-tailed T-test reveals that the difference is statistically insignificant in this case, with $p = .39$. Subjective learning results are similar to that of the monster truck, and with $p = .55$ show again that the construction quality of the demonstration appears to make no difference in the self assessed learning, (i.e. subjective comprehension). Finally, subjective enjoyment measures for the receiver tutorial revealed a distinct preference for the raw version of the demonstration over the polished demonstration, with $p = .026$ for the two tailed T-test. Clearly the small size of the groups being compared in this study makes it difficult to detect statistically significant differences between the raw and polished demonstrations and more data is needed before any final verdict can be made concerning the efficacy of raw versus polished demonstrations.

An important feature of the laser communicator demonstration that provides some insight as to the post-lecture quiz scores is the absence of the ability to modify the electrical components and observe the effects. In the monster truck demo, students could easily touch the springs and shock absorbers to aid in their learning process. In the communicator demo, no means to examine the voltages in the transducer stage or filtering stage was provided. Furthermore, resistors and capacitors were fixed eliminating the possibility of changing the dynamics of the system; an extremely important capability for any active learning paradigm. In part this explains the relatively weak scores on objective learning from the laser communicator case in comparison with the scores for the monster truck demo. It is conceivable that both the raw and polished versions of the laser communication demo could deliver higher objective learning scores if additional inputs and outputs were provided to reinforce students' learning. The statistically significant difference in subjective enjoyment observed in the current work is still of interest though since it shows that for two functionally equivalent demonstrations, students enjoyed using the raw demo more than it's polished counterpart, and are more likely to remain motivated for learning.

## Conclusions

In this investigation, the effect of demonstration construction quality on learning was examined with two case studies; a monster truck demo for illustrating mechanical vibration concepts and a laser communicator demo to motivate electrical circuit and signal processing concepts. While the general trend established showed that raw demonstrations were superior to polished demonstrations for all measures of learning, small sample sizes for the laser communicator study could not establish that the observed differences in objective comprehension between raw and polished demonstrations were statistically significant. Additional data will be gathered in the future in order to obtain better resolution on the laser communicator results. It should be emphasized that in all cases, students' subjective enjoyment of a lecture was higher for raw demonstrations than for polished demonstrations, and that this result was statistically significant with a p value less than .01 for the monster truck study and a p value of .026 for the laser communicator study. This finding is especially relevant, since it shows that students' interest in any given lesson is enhanced through the use of raw demos as opposed to polished potentially expensive demonstration equipment. In the final analysis this suggests that the use of fairly primitive demos built in-house on a small budget may be a much more cost effective way to stimulate students' interest than commercial quality demonstration equipment.

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Appendix I: Monster Truck Quiz

Name_____________________ Instructor ____________________ Date _______________

1. What is your major field of study (e.g. biology, IS, English) and year (e.g. fresh/soph/junior/senior+)?

   Field________________________________ Year __________________________________

2. How did the demonstration of the model car affect your interest in the subject matter
   a) The demo made me much more interested in the lecture material; I'm likely to find out more about suspension systems on my own time because of it.
   b) I found seeing the demo made me more interested in hearing the talk about suspension systems. Still, I doubt I'll be Googling to learn more about suspensions systems in the near future.
   c) The demo was interesting in itself but didn't make me want to learn about suspension systems, either in the talk or outside of class.
   d) The demo was lame and reinforced my opinion that I just wasted 10 minutes of my time.

3. How did the demonstration help you understand the subject matter?
   a) Having a chance to examine the demonstration clarified some things that I would probably not have understood from the lecture alone.
   b) Having a chance to examine the demonstration showed me that I correctly understood the material about springs and dampers taught in class but didn't help me learn anything new.
   c) The demo might be cool looking, but it didn't really help me understand anything about suspension systems.
   d) I honestly didn't bother to look at it much.

4. A car goes over a pothole and continues to bounce up and down for 15 seconds. The problem is
   a) Springs too strong
   b) Springs too weak
   c) Dampers too strong
   d) Dampers too weak
   e) There is no problem; this is normal behavior

5. A street car needs to have its suspension changed to make it competitive on a smooth race track. Its springs should be made
   a) harder
   b) remain unchanged
   c) softer

6. A new car design tends to bounce too quickly. What changes could be made to the dampers to fix this?
   a) make them easier to compress
   b) make them harder to compress
   c) you can only change the speed that the car bounces by changing the springs, not the dampers.

7. A new car design tends to ride too "rough", meaning on bad roads the passenger cab vibrates too much. What parts might need to be redesigned to fix this?
   a) The dampers and the springs. They are interrelated.
   b) Only the dampers. The springs do not affect ride roughness.
   c) Only the springs. The dampers do not affect ride roughness.

8. How would your car's suspension feel if the springs snapped and fell apart?
   a) very hard since the suspension would bottom out
   b) very soft since the suspension would now ride on the soft dampers

9. How would your car's suspension feel if the dampers broke?
   a) very hard since the suspension would bottom out
   b) very bouncy since the suspension would be ride on the bouncy springs

10. If a car hits a pothole, it will tend to bounce at a particular frequency (that is, cycles per second) set by the springs and dampers. How would this frequency change if the car was transported to the moon?
   a) bounce at a lower frequency
   b) unchanged
   c) bounce at a higher frequency

Appendix II: Laser Communicator Quiz:

Name_____________________ Instructor ____________________ Date _______________

1. What is your major field of study (e.g. biology, IS, English) and year (e.g. fresh/soph/junior/senior+)?

   Field________________________________ Year __________________________________

2. How did the demonstration of the laser communicator affect your interest in the subject matter
   a) The demo made me much more interested in the lecture material; I'm likely to find out more about communication systems on my own time because of it.

b) I found seeing the demo made me more interested in hearing the talk about communication systems. Still, I doubt I'll be Googling to learn more about communication systems in the near future.
c) The demo was interesting in itself but didn't make me want to learn about communication systems, either in the talk or outside of class.
d) The demo was lame and reinforced my opinion that I just wasted 10 minutes of my time.

3. How did the demonstration help you understand the subject matter?
   a) Having a chance to examine the demonstration clarified some things that I would probably not have understood from the lecture alone.
   b) Having a chance to examine the demonstration showed me that I correctly understood the material about photodiodes and filters taught in class but didn't help me learn anything new.
   c) The demo might be cool looking, but it didn't really help me understand anything about communication systems.
   d) I honestly didn't bother to look at it much.

4. What does the filter stage of receiver circuit do to the positive voltage signal from the photodiode?
   a) amplifies it by a factor of 10
   b) converts to a digital form
   c) Removes constant voltage components from the photodiode signal
   d) Removes high frequency components from the signal

5. Current flow through the reverse biased photo-diode:
   a) decreases as the light intensity on the photo-diode increases
   b) remains unchanged
   c) increases as the light intensity on the photo-diode increases

6. If the filter stage capacitance is held constant at 2.2 micro-Farads, what statement best describes the behavior of the filter after the resistance is increased?
   a) The filter passes lower frequency components than it did initially as the resistance increases
   b) The cut-off frequency of the filter increases as the resistance increases
   c) The cut-off frequency remains the same as the resistance increases

7. Which statement about the amplifier stage is false:
   a) The amplifier multiplies the voltage signal applied to it by a factor of 10.
   b) The amplifier draws an insignificant amount of current from the filter stage.
   c) The amplifier requires no external power source.
   d) The speaker draws too much current to be powered by the photo diode alone; a power amplifier is necessary

8. What would happen if we removed the capacitor from the filter stage of the receiver?
   a) nothing at all
   b) The voltage applied to the amplifier would have 0 mean value
   c) The voltage applied to the amplifier would be positive at all times

9. If the voltage used to reverse bias the photo-diode is increased to 10V, for a given light intensity
   a) the current through the photodiode increases
   b) the current through the photodiode decreases

10. The human ear can detect frequencies from 20 to 20000 Hz. What cutoff frequency should you use for the filter stage?
    a) 2000 Hz
    b) 1 Hz
    c) 10 Hz