An Intuitive Approach to Teaching concepts in Engineering to a General Audience

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Abstract

This paper focuses on a visual and intuitive approach to explaining concepts in engineering and technology. The method is based on establishing students' intuition by providing visual relevance-based content before focusing on mathematical understanding. The goal is to help students develop a core understanding of the subject matter, leading to an easier transition to deeper mathematical analysis. As the objective is to teach difficult concepts with little to no use of math or physics, the content could help introduce a general audience to concepts that otherwise seem exclusive. It is part of a larger program at Florida Atlantic University that targets multiple topics and concepts in engineering, computer science, physics, and mathematics.

The method was employed over the course of a semester for a class titled "Control Systems 1". A small scale assessment was applied to gauge the students' receptiveness to the techniques. Although the project is in the preliminary stages, the feedback has been positive. Currently, further efforts are being made to assess students throughout the course of the semester, comparing their overall success with their opinion of the techniques highlighted in the project.

1. Introduction

"Visual literacy in the classroom has become increasingly important as more and more information is accessed through technology. Students must maintain the ability to think critically and visually about the images presented to them in today's society" [1].

–Timothy Gangwer, Visual Impact, Visual Teaching: Using Images to Strengthen Learning (2009)

As the newer generations are developing with a greater access to interactive media, via the internet and smart phones, they are rewarded with information delivered in an instantaneous fashion. This may be why web developers are noticing a reduction of patience in web users. Studies have shown, most people leave web pages within the first ten seconds of viewing. Only if they decide to stay longer than 30 seconds does the probability of them staying on longer than a minute level out [2]. This reduction in patience has also been noted by Microsoft as they reported that users visit websites less if the site takes at least 250 milliseconds longer to load. "Two hundred fifty milliseconds, either slower or faster, is close to the magic number now for competitive advantage on the Web," reported Harry Shum, computer scientist at Microsoft [3]. In addition, it is reported that the majority of people are developing as visual learners. In a study by 3M Corporation, data showed that the brain processes visual information 60,000 times faster than text and that using visual aids in the classroom improve learning up to 400 percent [4].

Whether technology is the culprit, teachers are noticing a greater percentage of students having difficulty understanding key concepts from difficult coursework. Tyler DeWitt, high school teacher and Ph.D. student at MIT, noticed this phenomenon occurring with his high school chemistry students. As he taught the class, some of his favorite topics in chemistry, he noticed students did not understand the content, regardless of prescribed book reading and well thought out lesson plans. He became aware that even his top students were failing to understand key concepts. In response, he developed a style of teaching that is designed to engage students, making the subject matter more fun for the audience. This dialogue can be found in the TED Talk titled "Hey Science Teachers: Make it Fun!" [5]

Building on the success of instructors such as Tyler DeWitt, an approach has been developed to cater to students' increasing demand for teaching techniques which focus on visual and engaging styles of learning. Specifically, it is aimed at providing a "non-intimidating," "math-less" approach, by implementing a series of analogies and visual aids that relate everyday life to theories in difficult topics in STEM programs. Although this approach has existed among educators, there seems to be a lack of literature on the topic, especially in the areas of STEM and engineering. It is important to note that this is not meant to be a replacement to existing

textbooks, but supplementary material aimed at reinforcing understanding and enhancing intuition.

The methods employed and highlighted in this paper were implemented over the course of a semester on a senior level engineering class titled, "Control System". An assessment was created to gauge the effectiveness of the teaching styles employed. As the assessment is small scale, catering to a specific audience of senior level engineering students, further analysis must be conducted to ensure the effectiveness of the methodology.

2. Methodology

An explanation of a concept starts off by presenting students with a familiar experience in their everyday life. The scenario is explained by employing analogy to help students understand and relate to the problem at hand. Once completed, the components of the analogy are compared to elements of a topic in engineering. Visual aids, such as illustrations and graphs, are used to reinforce the text and provide students with their need for a visual style of learning. Below are a couple of examples that utilize this method for various topics in Control Systems.

Example for Explaining the Concept of Time Constant

Imagine you were taking a trip from Florida to Maine. You have three vehicles to choose from: a sports car, mini-van or a truck. The sports car would offer performance and fun but requires high octane gas and offers little storage room. The truck would be roomy and provide storage space at the price of poor MPG and horrible acceleration. The mini-van is not necessarily the best at any one category but is well rounded and suited for the job. Based on the familiar letter grading system in figure 2.1 below, which vehicle would you choose?

Figure 2.1: Automobiles displayed with graded attributes

You probably chose the minivan, since it has the highest average grade of the three attributes. These ***trade-offs*** are common in engineering. You cannot always afford to have the best of every world, so you must decide which solution fits your task best. As in engineering and most things in life, "there is no such thing as a free lunch".

On this trip, you encounter a red light on a three lane avenue. Coincidentally, stopped in each lane are the very cars you have at home. Which do you get behind? Most people would pull up behind the sports car. Its low profile allows you to sense more in front of it and its speed allows for little delay between the green light and your ability to take off.

You notice that each vehicle has a different acceleration once the light turns green. As each vehicle reaches the speed limit at different times, each system is said to have a different ***time constant***. In other words, the time constant serves as an indication for the time it takes the cars to reach a certain speed. In figure 2.2 the lengths of the different arrows are an indication for the relative acceleration of each vehicle, and the color helps to indicate which one is "better," i.e., green is best and red is worst.
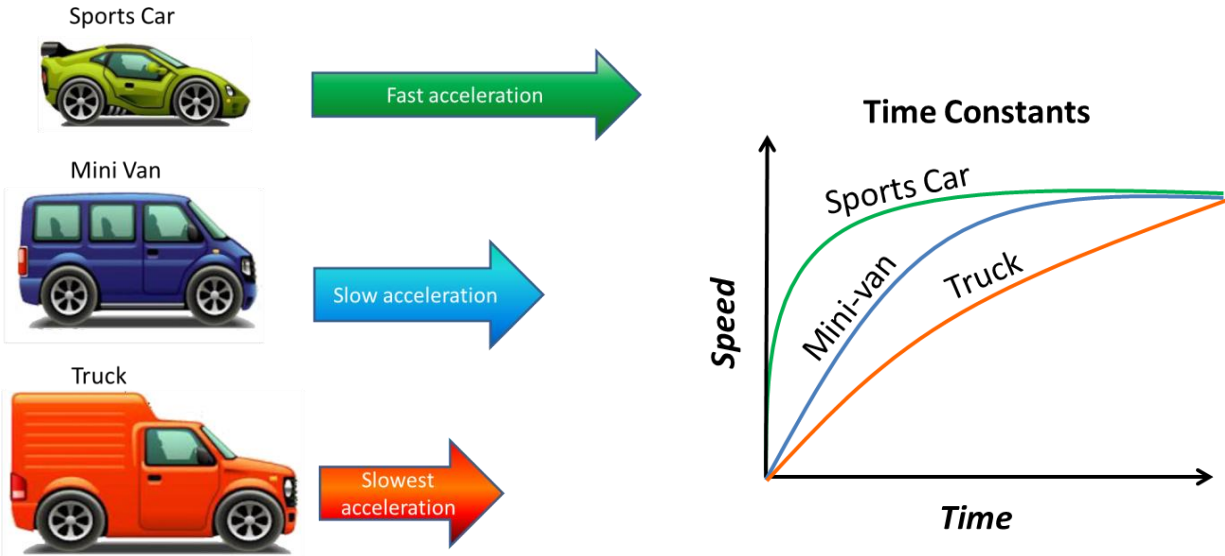
Figure 2.2: Automobiles acceleration with relation to their time constants

As the truck is the heaviest and the slowest of the three vehicles, it carries the largest time constant. The sports car is the fastest due to light weight, high horsepower and most likely a driver with a passion for speed, it carries the smallest time constant. The mini-van by default falls in the middle. This is clearly shown in the color matching graph in the left part of Figure 2.2

Example for Explaining the Concept of Time Delay

While standing on the curb, you notice three vehicles of the same make and model, with very similarly behaving drivers. They are all lined up in the same lane at a red light. As the light turns green, they all accelerate at the same rate but at different times as illustrated in figure 2.3.
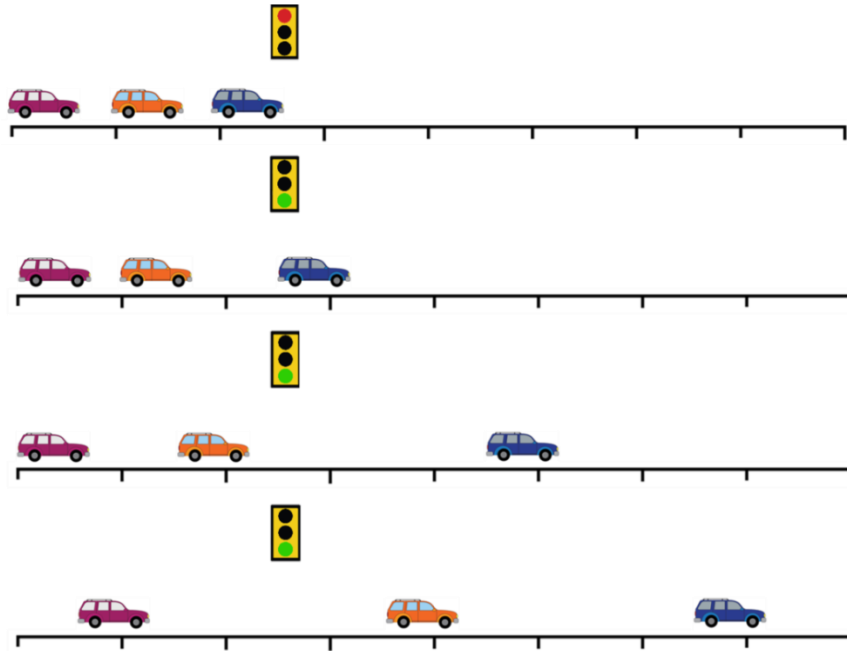
Figure 2.3: Position of all cars from totally stopping to full motion

The waiting time is considered a ***time delay***. Nothing was different from car to car except for the start time. Figure 2.4 illustrates that the cars have the same behavior with different time delays.
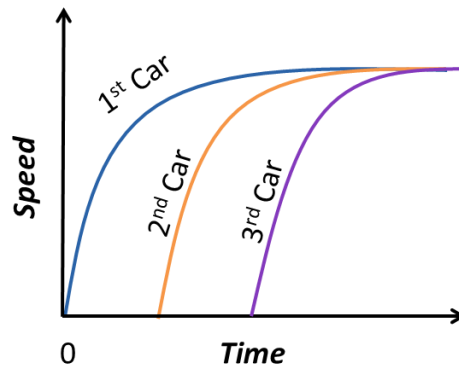

Figure 2.4: Graph representing behavior of similar systems with different time delays

Time delays are critically important in many systems. The airbag is a good example. For an airbag to be effective, it must be fully inflated within a fraction of a second after impact. If deployed two seconds after the crash it would only be effective in adding insult to injury. It is safe to say, an airbag must have a very short time constant (Figure 2.5).
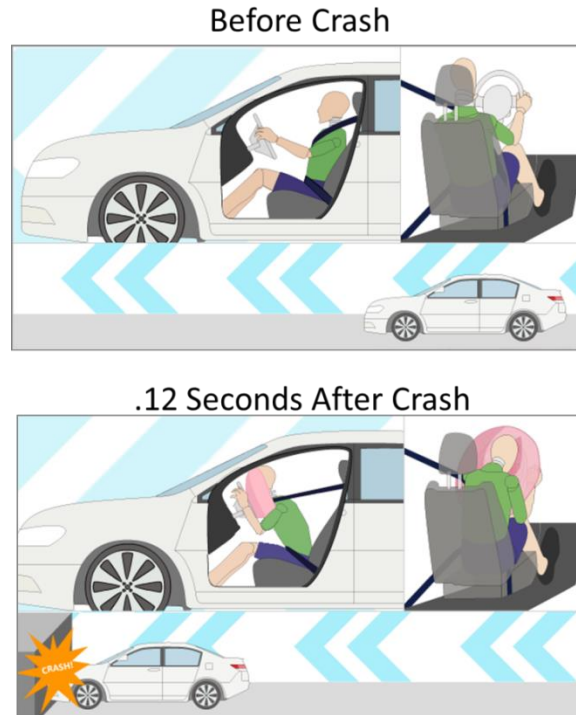
Figure 2.5: Graphic depicting the time delay of an air bag

Imagine you are in a dealership and the salesman tells you that the brakes have a three second time delay. Would you be willing to pay your hard earned money for it?

Figure 2.6: Shady used car salesman

Example for Explaining the Effect of Sensor Latency on Feedback System

It is not uncommon for Israeli engineers to use visuals and everyday examples for teaching concepts in STEM. The following example was inspired by a control systems book titled,

"Introduction to Controls", published in Hebrew [6]. Although the Israeli textbook uses visuals, it requires a requisite in math and physics. Below is an example similar to one found in the book. As the original example was taught alongside equations and block diagrams, the modified example below is more heavily illustrated, using no math. The concept is also explained in a way that avoids using jargon specific to electrical engineers.

A sensor's job is to feedback information to a system in order to correct errors that may exist. The quicker a sensor reports error to a system, the more accurately the system is able to compensate for it. For this reason, sensor placement is of great importance.

For example, imagine there is a factory that made cookies. The cookie dough is squeezed through a pump and on to a conveyer belt. To ensure the pump is squeezing out the right amount of dough, a sensor that measures the size of the cookies located below (Figure 2.7) is placed at the end of the conveyer belt. Do you see a problem with this?
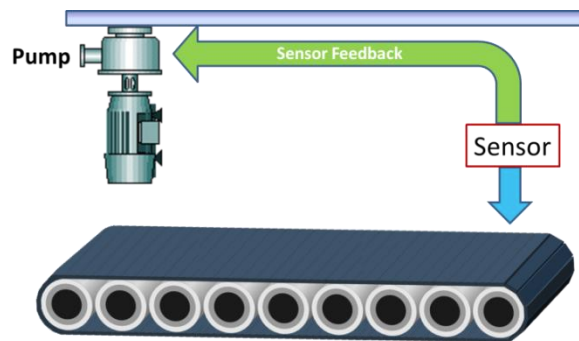

Figure 2.7: Conveyer belt with improper sensor placement

As you may have guessed, the sensor is placed too far from the pump. "So what?", one may ask. If the pump is making the cookies too big or too small, the pump would not find out until a number of cookies later. Suppose the example below, where the pump starts off making the cookies too small (Figure 2.8).
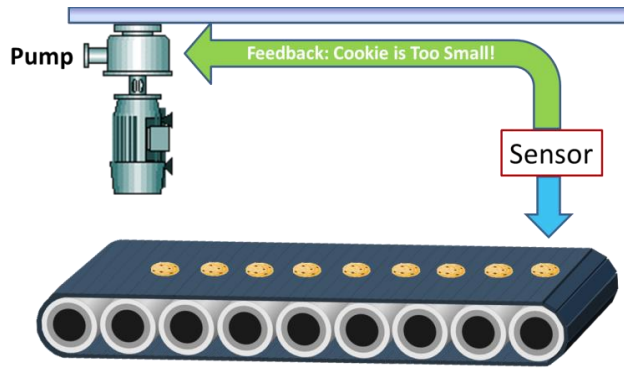
Figure 2.8: Conveyer belt producing cookies too small in size

In this scenario, the sensor would inform the pump of the wrong size after nine cookies were already made. At this point, the sensor would inform the system to increase the output, making the cookies bigger.
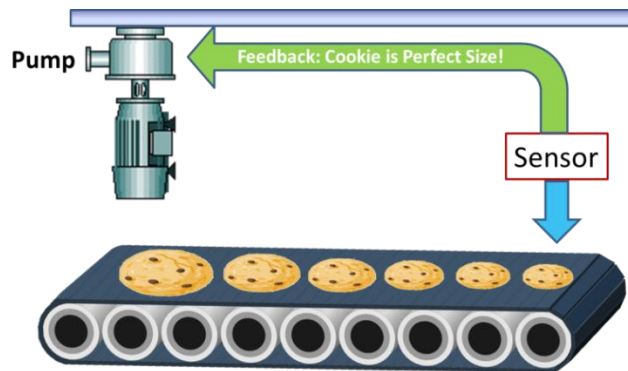

Figure 2.9: Conveyer belt producing cookies too large

Once the sensor reports to the system that the size is perfect, the pump has already increased the size much larger than desired. Once the sensor discovers the error, it will inform the system that it needs to decrease the size (Figure 2.10).
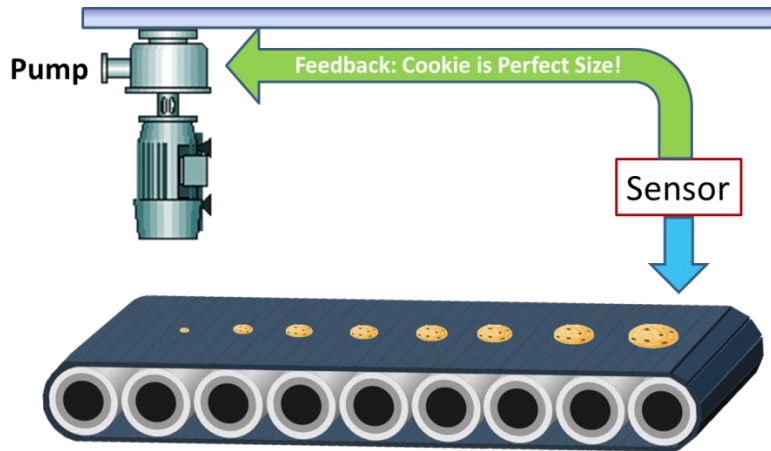
Figure 2.10: Conveyer belt producing cookies too small

Because the delayed response causes this back and forth, the system would continue to oscillate forever, never settling on its desired output. The graph below illustrates the changing cookie size as it goes from too small to too large, never settling on the desired size (Figure 2.11).
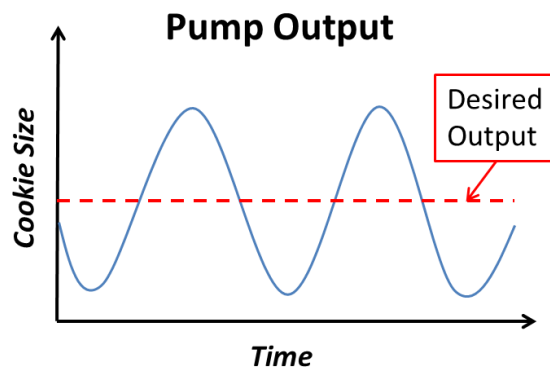

Figure 2.11: Graph displaying the size of the cookies being produced with time

A Solution:

Placing the sensor at the base of the pump, will ensure that the feedback is instantaneous, allowing the systems output to reach its desired settling point, i.e., the desired cookie size. The graph below titled "Pump Output", displays the size of the cookies over time when the sensor is placed at the base of the pump. Looking at figure 2.12, notice that the cookie size becomes constant once it reaches the desired output.
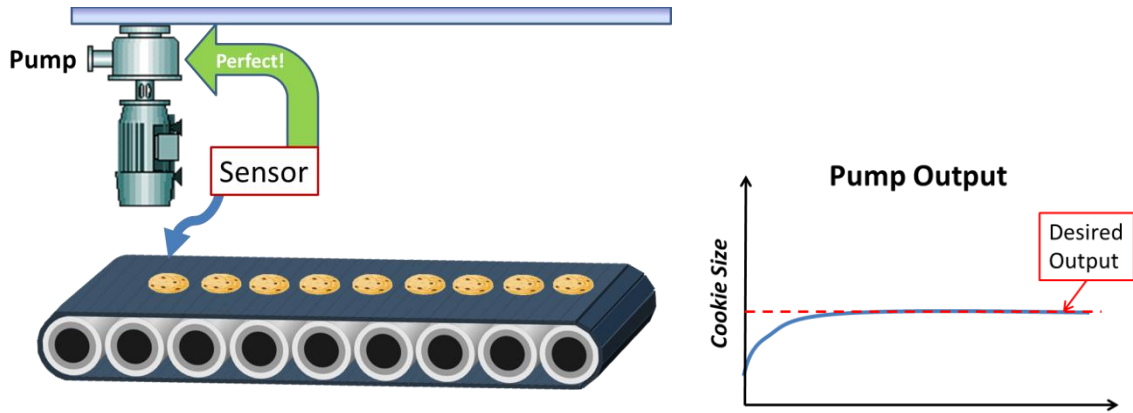
**Figure 2.12:** Conveyer belt with proper sensor placement with graph displaying desired behavior

Example of Engaging Activities for Teaching the Concept of Stability

Another technique used to clarify/explain concepts is to engage students during class by proposing a simple experiment meant to serve as positive reinforcement. This aids students in understanding concepts by fun, hands-on activities. The following is an example of how to engage students while reinforcing the concept of a topic in Control Systems called *stability*.
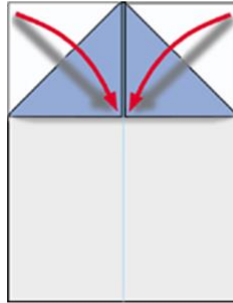
Try on your Own!

If you want to see stability in action, start by making a paper airplane. Forget how to do it? Here is a sample instruction in figure 2.13.
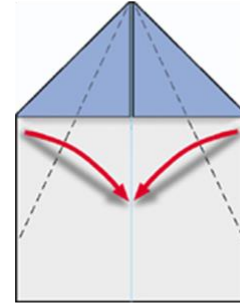
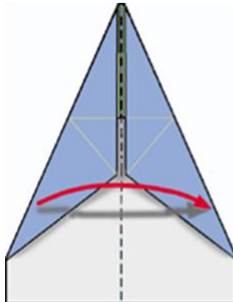**Step 1:** Fold an 8.5 x 11 paper in half lengthwise, then unfold the paper
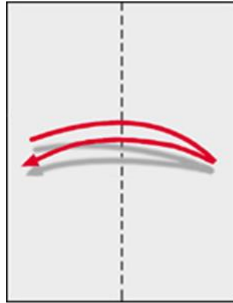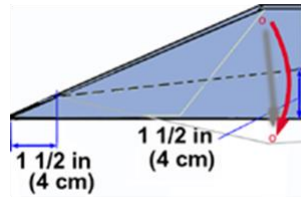
Step 2: Fold down two corners.

Step 3: Fold two edges toward the center as indicated

Step 4: Fold the plane in half

Step 5: Fold down two flaps, leaving about an inch and a half at the bottom.

1 1/2 in (4 cm)

1 1/2 in (4 cm)

Step 6: Fold a small tail wing on each side
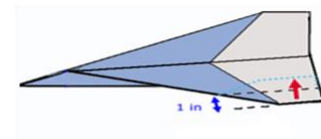
1 in

Figure 2.13: Instructions on building paper airplanes [7]

Now that you have a paper airplane, let's conduct a simple experiment. Place a paper clip on the front bottom edge of the plane. Now, fly it. The airplane should fly its normal, smooth pattern (Figure 2.14).

Figure 2.14: Flight pattern of airplane with paperclip placed in front

Now, place that same paper clip towards the back of the plane. The path should be distorted (Figure 2.15).
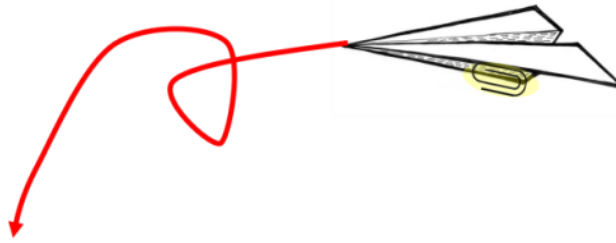
Figure 2.15: Flight pattern of airplane with paperclip placed in back

By adjusting the position of the paper clip, you are adjusting the so called "pole" of the system which in turn adjusts the stability of the airplane. A moving object has a center of pressure. When the weight is shifted towards the front of a plane, stability is increased. When the weight is shifted behind the center of pressure a plane becomes unstable.
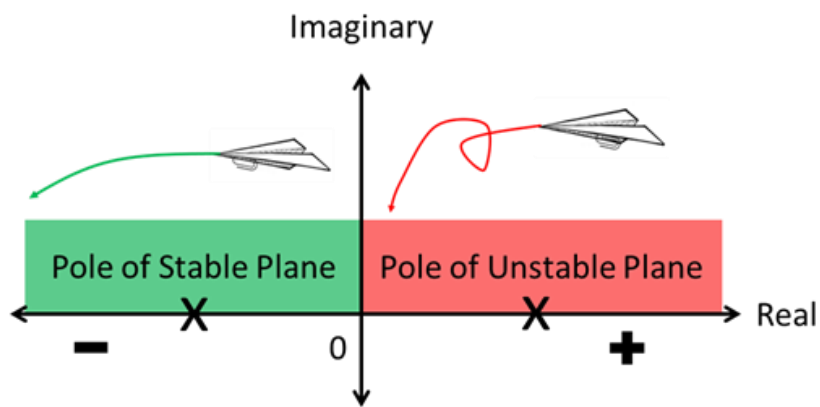

Figure 2.16: Pole location of paper airplanes

When taught in a classroom environment, students are prompted to throw the paper airplanes at the teacher once the clip is moved to the back, making them unstable. Teachers can confidently stand firm as students try to hit them because the airplane will never have the proper trajectory to nail its target. The activity is followed by a class discussion. As this approach keeps participants engaged and entertained, it also provides them with a lesson they are not likely to forget. This strategy has been highly effective in increasing the attention of students while reinforcing the concept of stability.

Figure 2.17: Instructor demonstrating concept of instability

The Use of Puzzles

To break the monotony of the using the same format throughout the manuscript, puzzles are also employed to keep students engaged. This not only serves as a way to keep the readers' attention but also provides them with a fun experience to further positive reinforcement. Below is a puzzle that reinforces the concept of stability.

Example of the Use of Puzzles for Reinforcing the Concept of Stability

A chicken farmer is hauling 5000 pounds of live chickens over an old bridge. Minus the weight of the truck and driver, the bridge will collapse under 2500 pounds of pressure. Realizing the instability of the bridge, the driver decides he will scare the chickens so that half of them will be flying in the air at any given time while he is driving over the bridge.

Will this tactic reduce the weight, preventing the bridge from collapsing?

Figure 2.18: Illustration of truck driver hauling chickens

Answer: No, because ideally the force of a chicken's takeoff would exert a downward column of air on the truck equaling the chicken's body weight. Although, some of this force may be distributed elsewhere, the truck would absorb most of the force, pushing its weight limit past the threshold of the failing bridge [8].

3. Assessment

The methods and examples highlighted in this paper were implemented in a Controls Systems class taught by a co-author of this paper at ____ University. An online questionnaire was conducted in order to gauge how receptive the students were to various learning techniques. Out of 33 students, data was collected on each individual's demographics. The figures found in the appendix display the detailed results of the survey.

Figures A.1-A.3, located in the appendix, indicate the demographic breakdown of the students who participated. The demographic breakdown showed a fair amount of diversity. Although most of the students were between the ages of 21-25, the class represented most age groups, 21 and older.

Note that the feedback from each question was typically skewed towards the students agreeing or disagreeing with a particular learning strategy. On a scale of 0-4, zero being strongly disagree, four being strongly agree and two being neutral, the response towards the question, "I feel that developing intuition for control is important" (figure 3.1) the average score was 3.66. While the students displayed their belief in the importance of intuition, they also displayed overwhelming support for the teaching styles implemented in the course that were designed to cater to visual learning. When asked the importance being able to visualize concepts as they learn, the total average score was above 3.6.

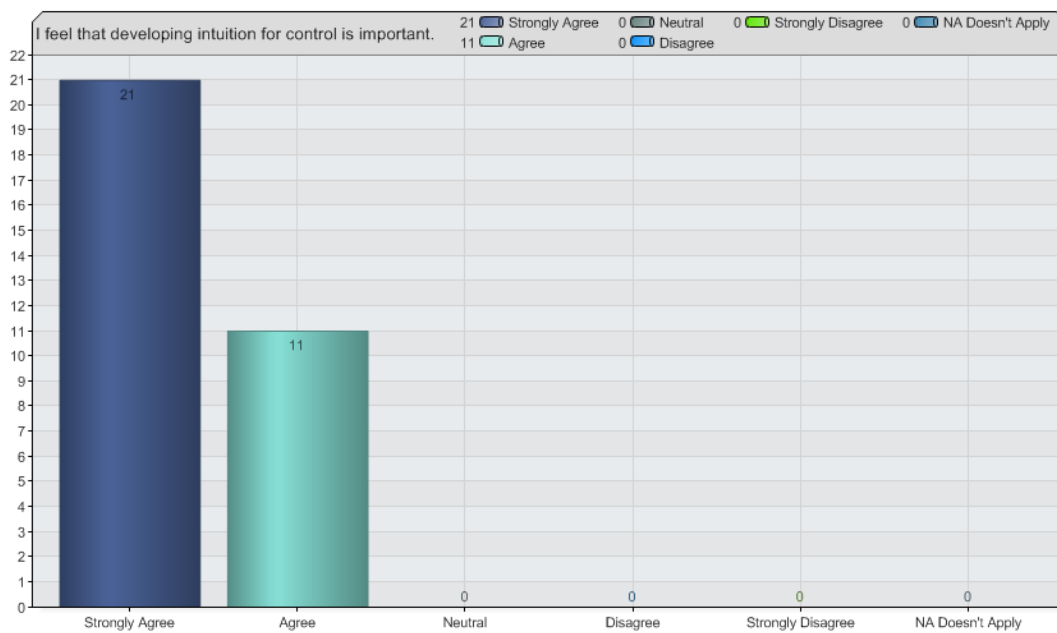Q: I feel that developing intuition for control is important

Figure 3.1: Student Feedback on importance of developing intuition for Controls

When asked questions on how the students preferred to be introduced to concepts in Control Systems, the results were in favor of engaging techniques such as visual, hands-on activities, 3D puzzles, and communication-based exercises, as each of those scored above 3.4. When asked if they preferred to be introduced to new topics in Controls by reading relevant chapters in a Controls text book, the total average was 1.9, which is below neutral. When asked whether they preferred to be self-taught, the total average was 1.3. This indicates that students prefer hands-on, engaging methods of learning difficult concepts to the conventional method of prescribed reading that is currently being employed.

Since the nature of the study is centered on a non-intimidating approach to Control systems or more generally, math- and science-related materials, students were asked how they characterized their math skills. Out of 32 answers, only four students felt their skills were modest while the remainder felt their background was strong or extremely strong. This statistic highlights that even students with strong backgrounds in math still feel that they benefit from engaging, visual- and intuitive-based learning. As these students are used to conventional methods of learning difficult concepts in a technology related field, they understand and denote the value of providing analogy and engaging examples to establish intuition before being taught the same concepts with math and physics. Since a primary goal of the manuscript is to provide a general audience, further analysis is required. The figure below highlights the class' competency in mathematics.
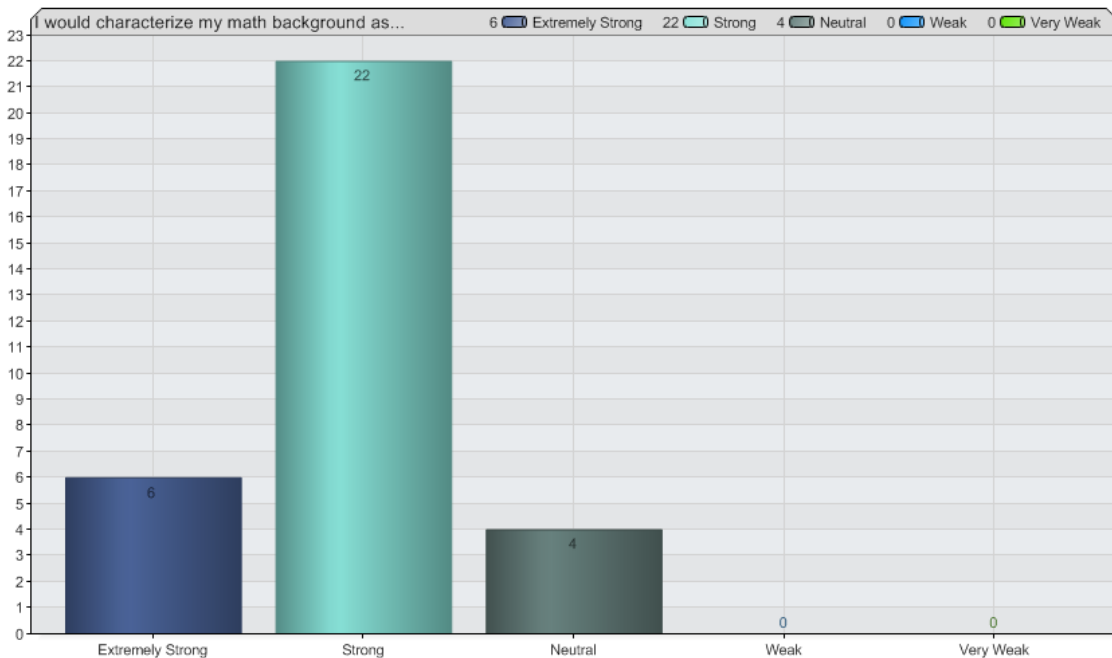
Q: I would characterize my math background as…

Figure 3.2: Student Competencies in Mathematics

As part of the questionnaire, students were also prompted to provide feedback to the question, "For future Control 1 classes, I would suggest to teach/learn in the following way:"

A1: "The way you teach the class is very good for learning."

A2: "The same way. The lecture notes which are available online are really helpful and the in class examples which really helps to understand the material"

A3: "With more hands-on examples or demonstrations in class"

A4: "The real life examples were essential for retaining the information. I liked the hands-on demonstrations in class"

A5: "Examples that focus on the big picture ideas. I liked the fact that Dr. _____ chose not to focus on material that Matlab or other software does for us (such as drawing Nyquist plots by hand), and instead focuses on the larger concepts."

Based on the survey questions and comments, the author feels that this approach is worth pursuing.

4. Conclusion and Ongoing Work

As technology brings about a paradigm shift, changing the way people perceive and learn information, methods must be explored to improve the success of students in the classroom, as well as encourage them to pursue difficult coursework in STEM. Since teachers are noticing students struggle with conventional methods of learning (i.e. text and math based examples), a method of providing students with visual, engaging material, aimed at solidifying intuition is proposed before the introduction of literature and math-based content. The methods described in this paper have been implemented as part of a senior level electrical engineering class titled "Control Systems". The approach was received with positive reviews. As these students were familiar with theory-based classes with heavy requisites in math and physics, the feedback provided is encouraging, Given the skill level of the students assessed, further analysis must be conducted to understand the effectiveness of the methods when introduced to a general audience. This is of importance, as introducing concepts in a way that can be read and understood by students regardless of discipline, remains a primary goal of the work. If students can have access to information that otherwise seemed exclusive, it may spark greater interest in STEM fields while alleviating their fear of learning perceivably difficult concepts.

This process is in the preliminary stages. There are additional goals as part of a larger scope to enhance students' understanding of difficult topics in STEM fields. In addition to creating a manuscript to serve as an introduction to existing materials in Control Systems, an effort is being made to convert the manuscript into an interactive, web-based manual. This will include videos, interactive activities, supplementary material, as well as links to relevant applications and existing math-based content once the reader has established intuition. An effort is also being made to do same with other subjects such as "Calculus", "Algorithms", "Estimation" and pertinent engineering software "MATLAB".

Acknowledgements

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[3] Lohr, Steve, "For Impatient Web Users, an Eye Blink Is Just Too Long to Wait", NY Times, 29 Feb 2012, Retrieved from: http://www.nytimes.com/2012/03/01/technology/impatient-web-users-flee-slow-loading-sites.html?pagewanted=all

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[7] Lee, Kyong. (2012) "Basic Dart Folding Instructions. Amazing Paper Airplanes". Retrieved from: http://amazingpaperairplanes.com/

[8] Magliozzi, Tom (1999), *A Haircut in Horsetown*, Perigee Trade

Appendix

The following figures are graphs containing the results from the questionnaire discussed in the assessment section.
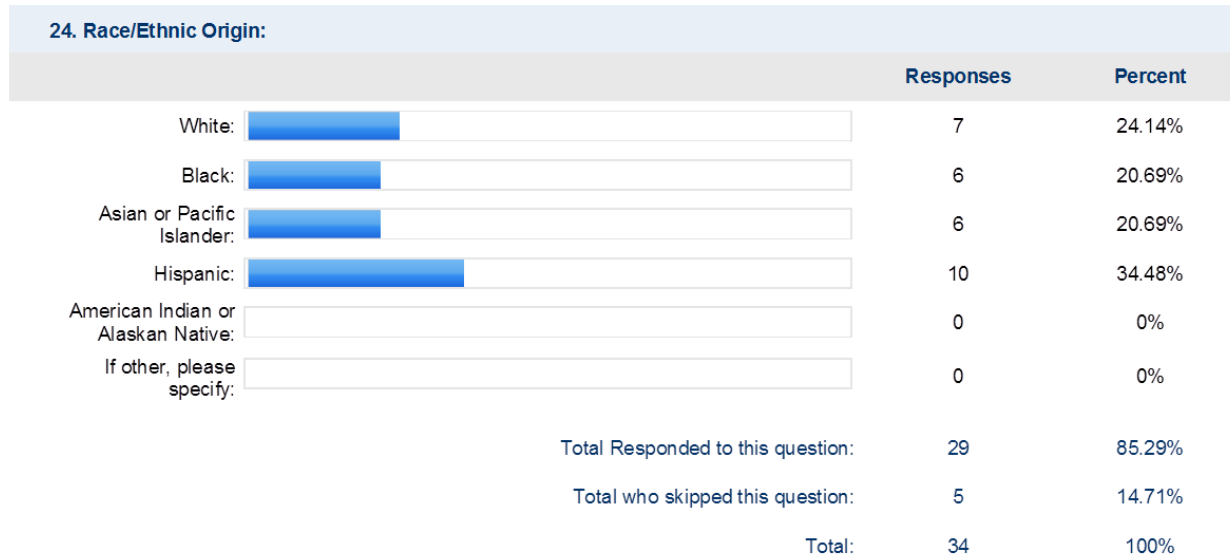
24. Race/Ethnic Origin:

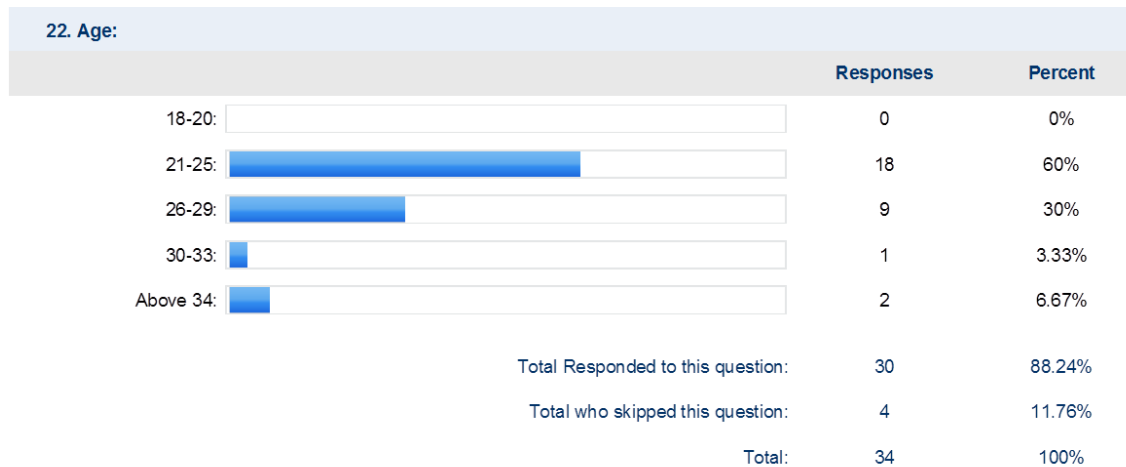|		Responses	Percent
White:		7	24.14%
Black:		6	20.69%
Asian or Pacific Islander:		6	20.69%
Hispanic:		10	34.48%
American Indian or Alaskan Native:		0	0%
If other, please specify:		0	0%
Total Responded to this question:		29	85.29%
Total who skipped this question:		5	14.71%
Total:		34	100%

Figure A.1: Ethnic Distribution

22. Age:

		Responses	Percent
18-20:		0	0%
21-25:		18	60%
26-29:		9	30%
30-33:		1	3.33%
Above 34:		2	6.67%
Total Responded to this question:		30	88.24%
Total who skipped this question:		4	11.76%
Total:		34	100%

Figure A.2: Age Distribution

23. Gender:

	Responses	Percent
Male:	25	86.21%
Female:	4	13.79%
Total Responded to this question:	29	85.29%
Total who skipped this question:	5	14.71%
Total:	34	100%

Figure A.3: Gender Distribution

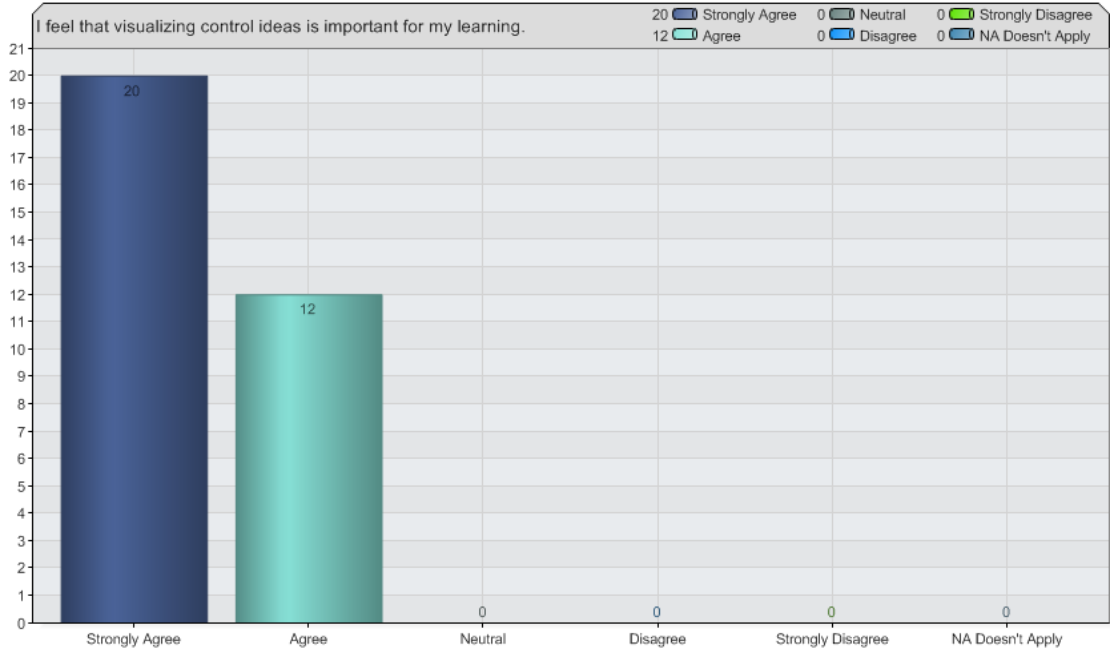Q: I feel that visualizing control ideas is important

Figure A.4: Student feedback on Visualization of Controls

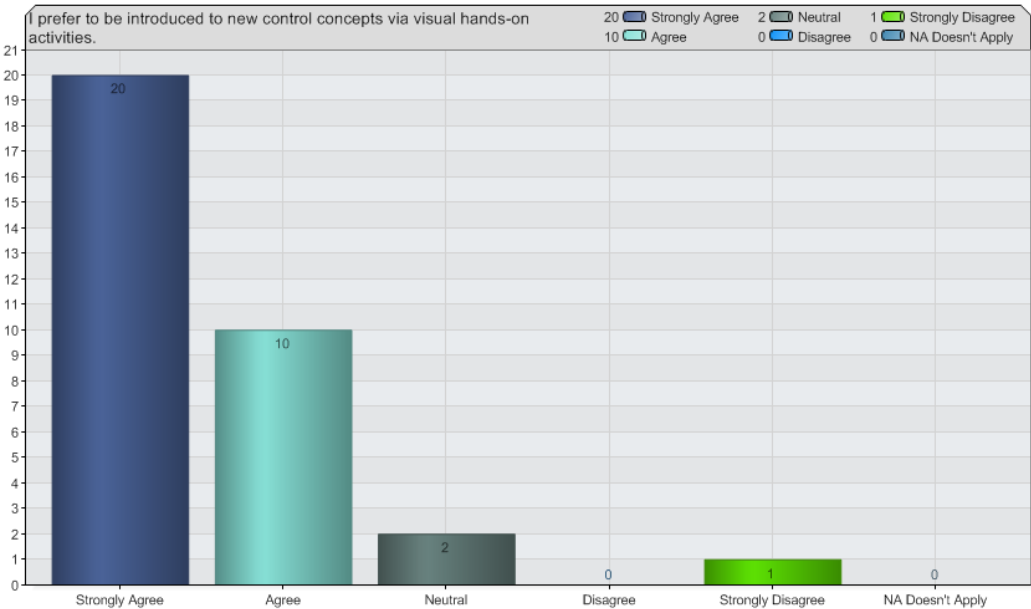Q: I prefer to be introduction to new control concepts via visual hands-on activities

Figure A.5: Student feedback on visual hands-on activities

Q: I prefer to be involved in communication-based exercises to intuitively understand control system concepts
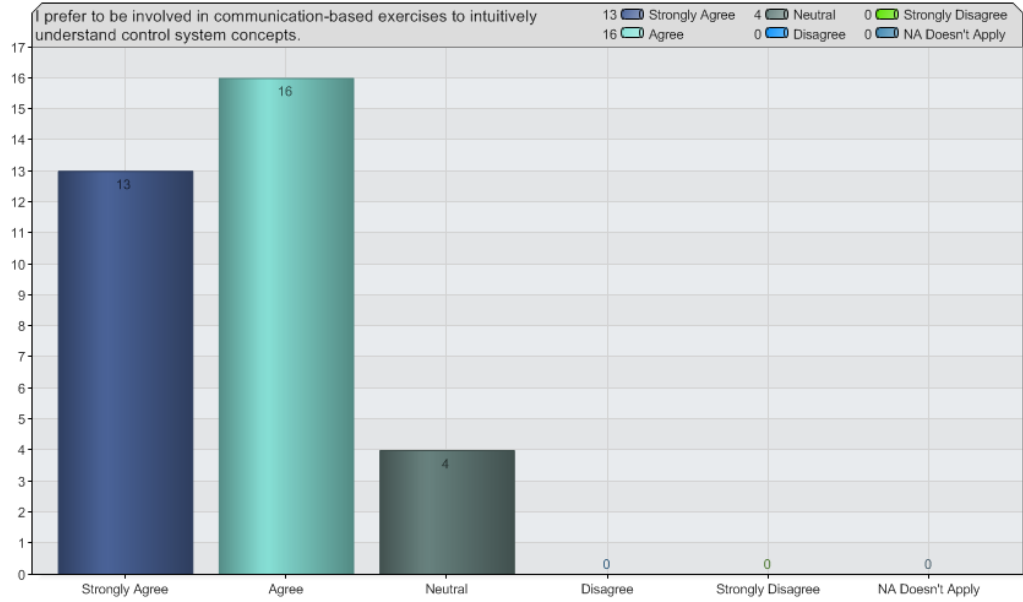

Figure A.6: Student feedback on communication-based exercises

Q: I prefer to learn control systems by reading class PowerPoint slides or transparencies
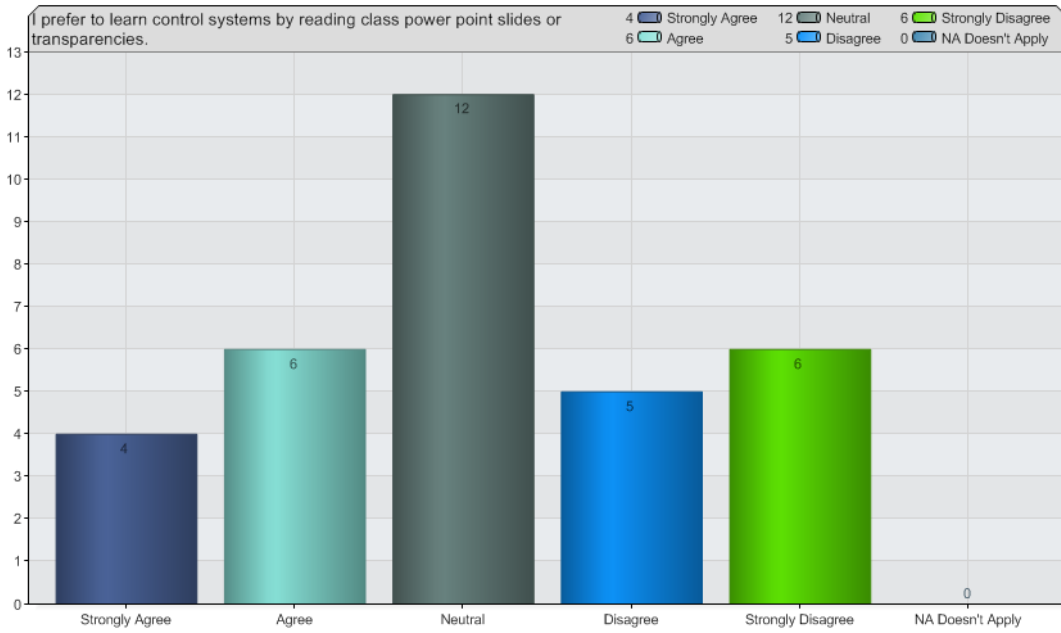

Figure A.7: Student feedback on learning by PowerPoint or transparencies
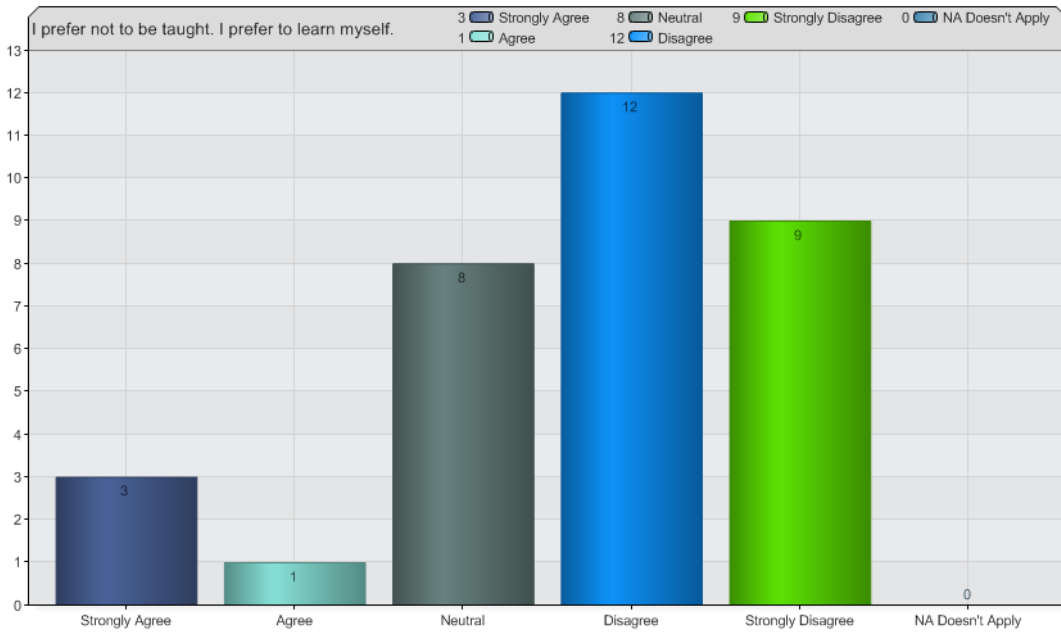
Q: I prefer not to be taught. I prefer to learn myself

Figure A.8: Student feedback on self-teaching

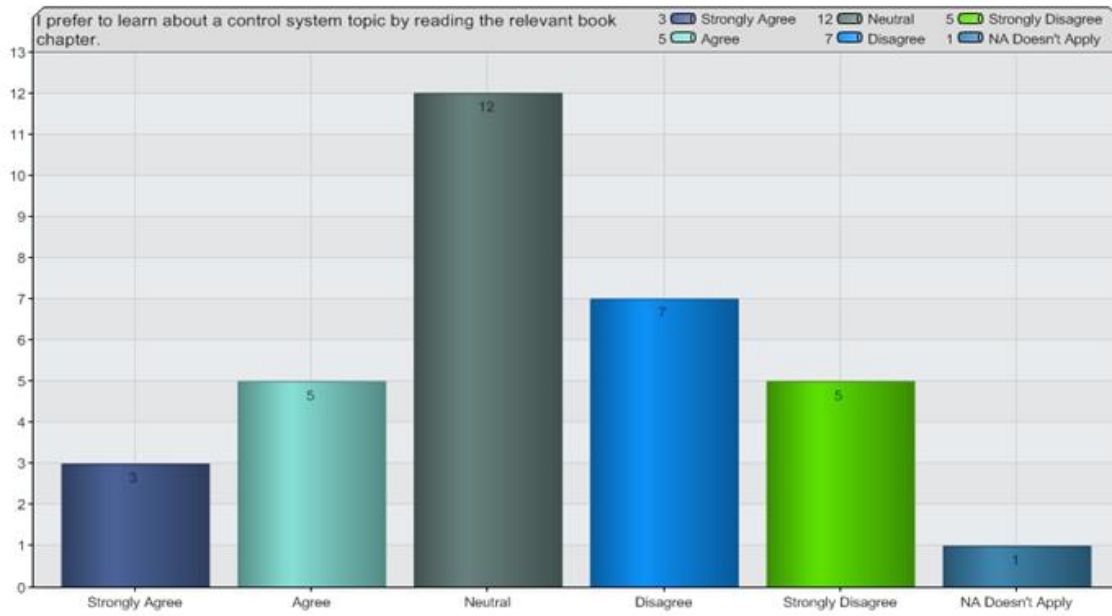Q: I prefer to learn about a control system topic by reading the relevant book chapter

Figure A.9: Student Feedback on learning by reading relevant materials