Experience-Based Approach for Teaching and Learning Concepts in Digital Signal Processing

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Abstract

This paper focuses on the use of daily real-life experiences to explain concepts in Digital Signal Processing (DSP). These concepts are presented in an intuitive and engaging manner through the use of visual examples, stories, interactive activities, animations, and puzzles. The paper focuses on the concept of sampling. Additional work on other DSP topics is ongoing.

Students are often times overwhelmed with the equations used to explain concepts in electrical engineering. Although it is important and valuable to understand the mathematics behind these concepts, many students comprehend ideas more effectively (at least initially) when presented with examples that relate to everyday life. DSP is clearly one topic that involves a great deal of mathematics. Unfortunately it is typically taught in a conventional lecture-focused theoretical manner, with a very few visual and intuitive examples.

This paper shares examples using a multi-modal visual approach. It focuses on the teaching and learning of sampling including under sampling, over sampling, and multi-rate sampling. The emphasis of this approach is on introducing the material in a way that allows students to easily grasp concepts by providing many daily experience-based,, real-world examples, images (and stories), animations, experiments, games, and puzzles. Specific examples in the paper are related to experiences such as driving, talking over the mobile phone, and entertainment. In addition, STEM-based examples, e.g., from medicine and physics are presented.

We have assessed students' response to the new way of learning, and received very positive feedback. In addition, in order to get a large set of examples, students have been given extra credit assignments that encourage them to explore and report on real-life topic-focused instances/activities. These assignments motivate students to think critically and also help them to better comprehend topics in DSP.

It should be emphasized that the work is not meant to replace an existing DSP textbook. Instead it is designed to be used as material that supplements the learning of topics in signal processing.

1. Introduction

With the continuously growing popularity of the internet has come a new era of learning and communicating. Information is now conveyed in a more visual manner. This has trained young minds to grasp concepts more effectively when presented in a way they could visualize [1].

Techniques similar to the ones discussed in this paper have been explored by other researchers and educators. A TED Talk was given by Tyler DeWitt, a PhD student at MIT and biology middle school teacher, on how he was able to improve the learning experience for middle school students [2]. DeWitt implemented a visual and intuitive approach to teaching the students in his biology class about viruses. DeWitt found that this approach was effective in getting middle school students to understand the topics and got them excited about science.

Due to the popularity of the smart phone, the answers to questions one may have are now at the person's fingertips at any given time. An educator might predict that students have the tools to learn concepts more avidly with access to the internet. However, learners still need to be interested in understanding a topic in order to make use of the tools they have access to. For that reason, it is important that difficult topics being taught should be introduced in an intuitive way that is not intimidating to the student. These techniques of teaching should also be visual in order to cater to this learning method increasingly being employed by more students.

In order to engage students in the learning of these topics, it is essential that the student makes a connection with the idea being conveyed. The way to do that is by providing examples that relate to everyday experiences. Many examples, stories, and experiments are presented in this paper. It is important to remark that this manuscript is not designed to replace existing textbooks that cover the topics in detail, instead it is meant to serve as material that reinforces the teaching of difficult concepts in digital signal processing.

The approach and methods described in this paper were implemented in a lecture for a senior level Electrical Engineering course called Introduction to Digital Signal Processing. The effectiveness of this technique was measured by giving the students a questionnaire and

compiling the results. In order to accurately quantify the success of these methods, more analysis is required.

2. Methodology

A concept is introduced by first providing a story that allows students to connect with a familiar experience. This story is then related to the concept by making use of an analogy that allows students to understand the idea. Then the elements of that analogy are correlated to the engineering topic at hand. Making use of visual aids is advantageous as it reinforces the example and caters to the students who have a visual learning style [3]. Below are examples to be used as an introduction for general sampling, under-sampling, over-sampling, and multi-rate sampling. These examples are strategically ordered with the basic examples at the beginning and the more complex examples at the end of each sub-section.

2.1. Examples for Explaining the Concept of Sampling

The following examples provide an introduction to sampling and analog-to-digital conversion. The examples range from entertainment to medicine and engineering. They cover time-domain and frequency-domain sampling while some touch on sampling in other domains.

2.1.1. Air Conditioner Thermostat

Your thermostat for your home air conditioning unit may be digital. If this is the case, you enter a whole number for your desired temperature. This number you entered is a discrete-time signal.

Your thermostat then sends control signals to your air conditioner so that it turns on or off in order for the house to reach the desired temperature. The actual temperature of your home is a continuous-time signal because it gradually changes from the original temperature to the desired temperature you indicated on the thermostat. However, the display shows only a set of discrete numbers, e.g., 70, 71, 72.

2.1.2. Analog and Digital Clock

Is it possible to tell the exact time (well, almost…) when looking at clock such as the one below on the left? Theoretically yes, if you had the ability to zoom in more and more, you could tell the time down to the milliseconds, microseconds, nanoseconds, and so on. This is called an analog clock which displays a continuous quantity [4].

Now, by looking at the clock below on the right, what time is it? It's seven o'clock, no questions asked. This is because the clock on the right is a digital clock. The time displayed by the clock is finite so it is a discrete quantity. The next display will be 7:01. We have no way to know the time between 7:00 and 7:01. In this case the display shows only samples of time.

Source: http://www.videomaker.com/article/14560-use-analog-to-digital-converters-properly

2.1.3. Surveying

One way we sample in order to get a representation is by surveying. To know how an entire population feels about something one may choose to survey a portion of the population at random. The data will be more accurate as you survey more relevant people within the population.

2.1.4. Doctor's Visit

Why do we get check-ups by doctors? It's because we want them to check our health. This can be thought of as sampling.

How often do you go to your primary care doctor? Most people visit the doctor every six months as long as they are healthy. Patients that are sick or have a health condition that the doctor needs to monitor closely visit the doctor much more often.

Sick patients have to check their health at a much higher sampling rate than healthy patients do.

2.1.5. Water Quality

Drinking clean water is important. For that reason there are facilities dedicated to testing the quality of the water. However, it would be overkill to test the quality of every gallon of drinking water. Instead the water quality is sampled by testing a portion of the water that is going to be used as this provides a sufficiently accurate estimate of the quality of the water.

2.1.6. Color Choosing at Art Store

The visible light spectrum contains an infinite amount of unique colors because this spectrum is continuous.

Source: https://www.wou.edu/las/physci/ch462/tmcolors.htm
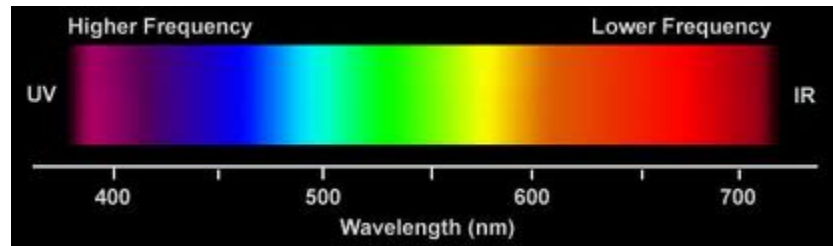
However, when you go to the art store to purchase paint there is a limited amount of options that are spread across the color spectrum. Therefore, one can sample the color spectrum by choosing the color of paint offered by the art store.

Source: http://diyonthecheap.com/how-to-choose-the-perfect-paint-color

2.1.7. Movie Trailer

Have you noticed that movie trailers can often encourage or discourage you from watching a certain movie? Movie trailers are created to give viewers a sample of the movie. Usually they are collections of movie samples to give the flavor of the whole movie.

2.1.8. Digital Radio

Nowadays, when you tune the radio in the car, you are doing it digitally so the broadband frequency of the radio station you are choosing is accurate to the nearest 0.1 MHz (if you are using FM). Note that a few decades ago the tuning of radios was all analog using a dial that you turned until you heard the desired radio station clearly; now the frequency of your chosen radio station is a finite, or of discrete value. You cannot tune to frequencies between say 89.8 and 89.9MHz.

Source: http://www.asia.ru/en/ProductInfo/1103137.html

2.1.9. A/D Converter Resolution

In electrical and computer engineering, a common peripheral device for a microprocessor is an analog to digital converter (ADC). This device converts an analog voltage (within a certain range) to discrete levels. Each ADC has a resolution defined by the number of bits.

Common ADC bit resolutions	Discrete Levels	Range
8	256	0-255
10	1024	0-1023
12	4096	0-4095
16	65,536	0-65,525

When using microprocessors, most analog voltages being measured are in the range of 0-3.3V or 0-5V. Each bit yields two discrete levels of resolution. A combination of multiple bits gives a number of discrete levels equal to two to the power of the number of bits (e.g. $2^8 = 256$).

For most applications, such as reading a value from a temperature sensor, a 10-bit ADC provides more than enough resolution (unless you need a temperature down to hundredths of a degree). In this case, using a 16-bit instead of 10-bit ADC for this application would be an example of oversampling because you are using more resolution than you need for the signal.

2.1.10. Potentiometer and Decade Resistor Box

In electrical engineering we make use of many components and devices. One of the most important components is the resistor. An engineer decides to test a particular circuit with different resistances. Picking several resistance values and plugging them all in and out of the circuit would be tedious. So two options come to the engineer's mind, one is to use a potentiometer and the other is to use a decade resistor box. If the engineer uses one side of the potentiometer and the center of it, he/she now has a continuously adjustable resistor or an analog variable resistor. However, if the engineer uses a decade resistor box (has several resistors in one box) he/she has a discrete adjustable resistor or a digital variable resistor.

2.2. Examples for Explaining the Concept of Under-Sampling

The following examples provide an introduction to under-sampling and aliasing. The examples range from entertainment to driving. These examples cover time-domain sampling.

2.2.1. TV Sampling

Did you know that the shows you watch on TV are not continuous-time signals? In fact, many years ago television was shown as a series of pictures or "frames." The frames were changed at a rate fast enough that your eyes wouldn't notice. This rate was 24 frames per second and has since increased. Why don't we notice this? The rate at which we sample and process the video is lower than the rate at which the frames change.

2.2.2. Backwards Spinning of Wheels

Have you ever looked at another car on the highway and seen the wheels spinning slowly or even backwards? Since our brain takes time to process the image, our vision has a limited sampling rate. As the other car goes faster the rotation of the wheels increases. With a high enough rotation speed of the wheels, it will seem as if the wheels are moving backwards. At even higher rotation speeds, it will seem as if the wheels are moving forwards but slowly. This phenomenon can be seen in the following YouTube video. In this case we are under-sampling, or sampling at a too low rate relative to the frequency of the wheel's rotation, and the wheels spinning backwards is our vision experiencing aliasing.

http://www.youtube.com/watch?v=jHS9JGkEOmA

In the image below, we see two cases (case A and case B). Remember our brain samples for image processing. Imagine you're looking at the wheel in case A, the first time you saw the wheel it was at position f1 and the next time you were able to make out the position of the wheel it was at f2. Since the position of the spokes of the wheels is closer to the initial position of any given spoke, you can confidently determine that the wheel is moving clockwise. Now imagine you're looking at the wheel in case B, the first time you saw the wheel it was at position f1 and the next time you were able to determine the position of the wheel it was at f2. In this case the wheel is in fact moving in the clockwise direction; however, due to the fact that the position of the spokes is closer to the following spoke it seems as if the wheel is actually moving in the counter-clockwise direction. This is happens because our sampling rate is too low. This phenomenon is called aliasing.

Source: http://www.sciencedirect.com/science/article/pii/S1364661305001117
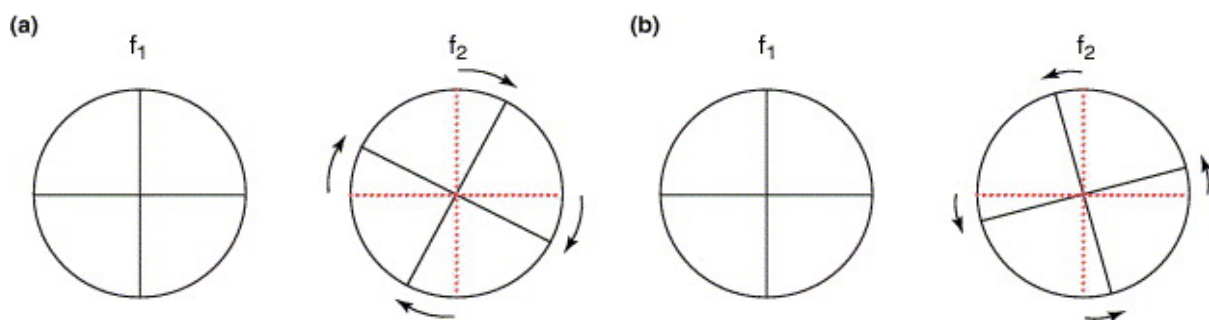
The following video shows a variety of cars with wheels undergoing aliasing and therefore appearing to spin backwards.

Source: https://www.youtube.com/watch?v=jHS9JGkEOmA

2.2.3. Helicopter Blade

The following video is an example of aliasing. Older video cameras had lower sampling rates. In this case the frequency of the helicopter propeller's rotations was by far higher than the sampling rate of the video camera. Because of this, the viewer experienced aliasing by displaying what seems to be a slow or backwards moving propeller.

http://www.youtube.com/watch?v=5ubP48xJZVw

2.2.4. Stroboscope

The following video shows how the use of a flashing light (stroboscope) forces our vision to see only the sampled images. The sampling rate, if it is low enough, makes a string that is rotating fast seem like it is rotating slow or backwards. This is an example of aliasing.

http://www.youtube.com/watch?v=A-19SxqZ8Qs

2.3. Examples for Explaining the Concept of Over-Sampling

The following examples provide an introduction to over-sampling. The examples range from everyday experiences to medicine. One of these examples covers time-domain sampling while the other covers sampling in another domain.

2.3.1. Checking Mailbox

Your mailman delivers mail to your home once a day. If you go to check your mail each night you will most likely find your mail there. You may also choose to check your mailbox multiple times a day but you will still find the same mail during one of those trips to the mailbox and (if you picked it up) nothing at all your other visits during the day. This is an example of oversampling, because you sampled more than necessary to retrieve the same information.

2.3.2. Blood Sampling for Diabetic Patient

Patients with Diabetes need to monitor their blood glucose levels several times a day. They do so by taking some blood, or sampling. A patient wants to know if their glucose levels are too high or too low but these changes in levels don't happen immediately. For that reason, poking themselves very often to sample their blood sugar is not necessary (and probably not desired) and would be a case of oversampling.
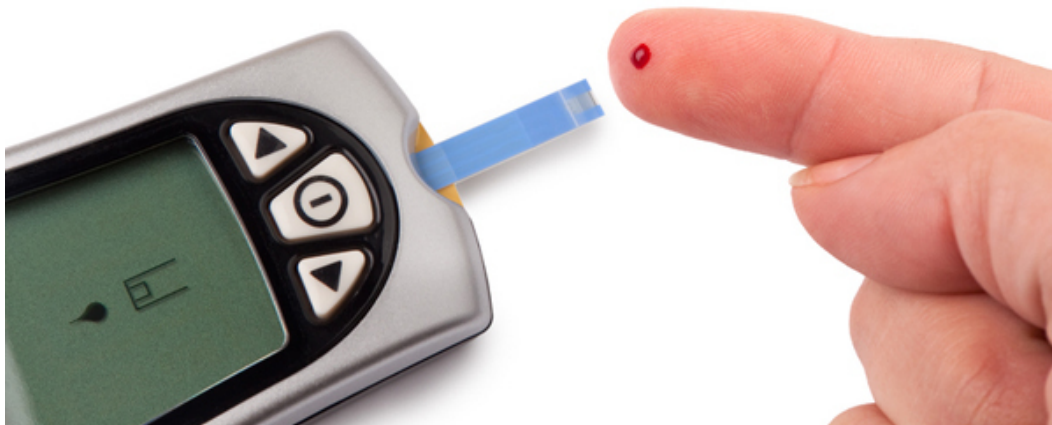
2.4. Examples for Explaining the Concept of Multi-rate Sampling

The following examples provide an introduction to multi-rate sampling. The examples range from entertainment to driving. These examples cover time-domain sampling while one example covers sampling in another domain.

2.4.1. Processing During Driving

It is much more relaxing to drive on a Sunday than it is to drive in a city during rush hour. This is because during rush hour traffic is moving and stopping often and other cars might be changing lanes aggressively so you have to be focused at all times while on a sunny Sunday afternoon when there are few cars on the road you get to drive with less focus. Essentially, you have to sample more while driving in rush hour than you do while driving on a Sunday.

Source: http://www.nuclearsalad.com/everything/correcting-these-driving-habits-brings-us-one-step-closer-to-world-peace

2.4.2. Looking for Address While Driving

Many of us have had to drive to unfamiliar places and use maps to find the destination. Have you noticed our tendency to drive slower and to lower the volume of the music in the car when getting closer to the destination? Why do you think that is?

While we drive towards the vicinity of where the destination is, we don't need to concentrate too much and might want to hear music as we drive. However, as we get close to the destination we've never been to, we have to concentrate more in order to find the address

without going in too many circles. During this period of concentration we feel the need to slow down and to lower the volume of the music because we want all of our sampling and processing to go into finding the location.

Source: http://www.wisegeek.org/why-do-some-gps-devices-have-bluetooth.htm

2.4.3. Soccer Goalie

Goalies in soccer have a large responsibility of not allowing shots into their net. However, while their team has the ball and is attacking on the other half of the field, the goalie gets to relax and sample less, as Jasper Cillessen (Goalkeeper of Netherlands) is doing. On the other hand, when a goalie wants to block a penalty kick the sampling rate is much higher as he or she must really concentrate. Interestingly, in professional soccer, goalies widely accept the fact that penalty kicks are kicked at a speed too high for a goalie to react to, so they have to guess which way to dive right before the ball is kicked and hope they guessed the right direction.

2.4.4. Hierarchy of Command in Corporation

The way executives communicate with managers and managers with lower level workers demonstrates multi-rate sampling. The CEO of a company may have a meeting with the Vice Presidents every two months to discuss progress and brainstorm ideas for the following quarter. Each Vice President may meet with the directors that report to him or her once a month to give feedback and future goals. The directors might meet with the managers every two weeks to share with them the plan of action. And the manager may meet with the workers once or twice a week

to give instructions. Here we note that there a different rates of sampling based on the position in the company the individual has.
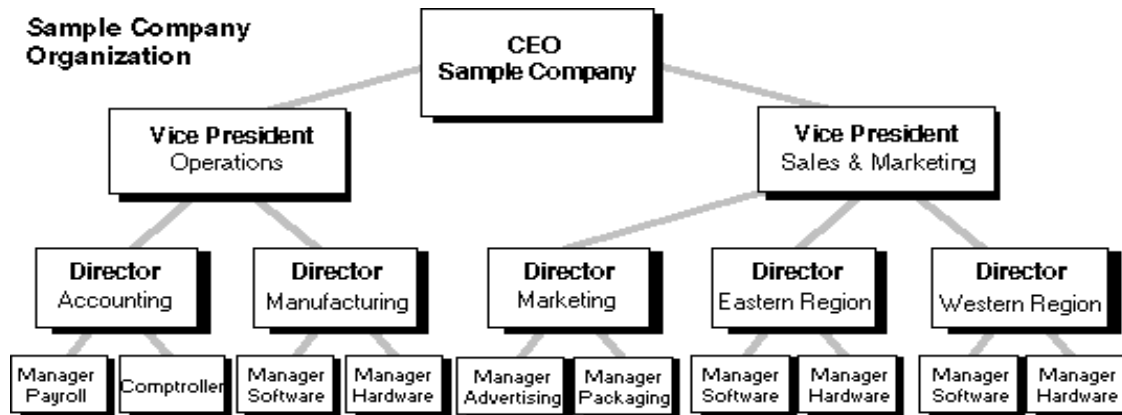
2.5. Sampling Experiments Used to Engage Students

The following experiments are meant to engage students while having them experience topics in digital signal processing. These experiments aid in the introduction of sampling and under-sampling.

2.5.1. Paper Drop

Take an 8 ½ x 11 piece of paper, fold it and cut it as shown below.
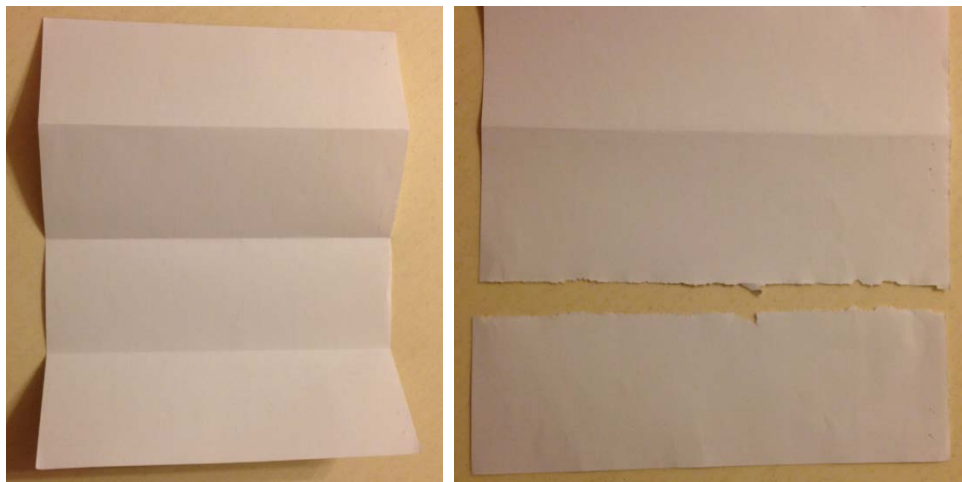
Now have a partner hold the paper from the top. Keep your fingers apart around the paper about two inches below your partner's fingers. Ask your partner to randomly let go of the paper. Are you able to catch the paper with your fingers before it passes your fingers?
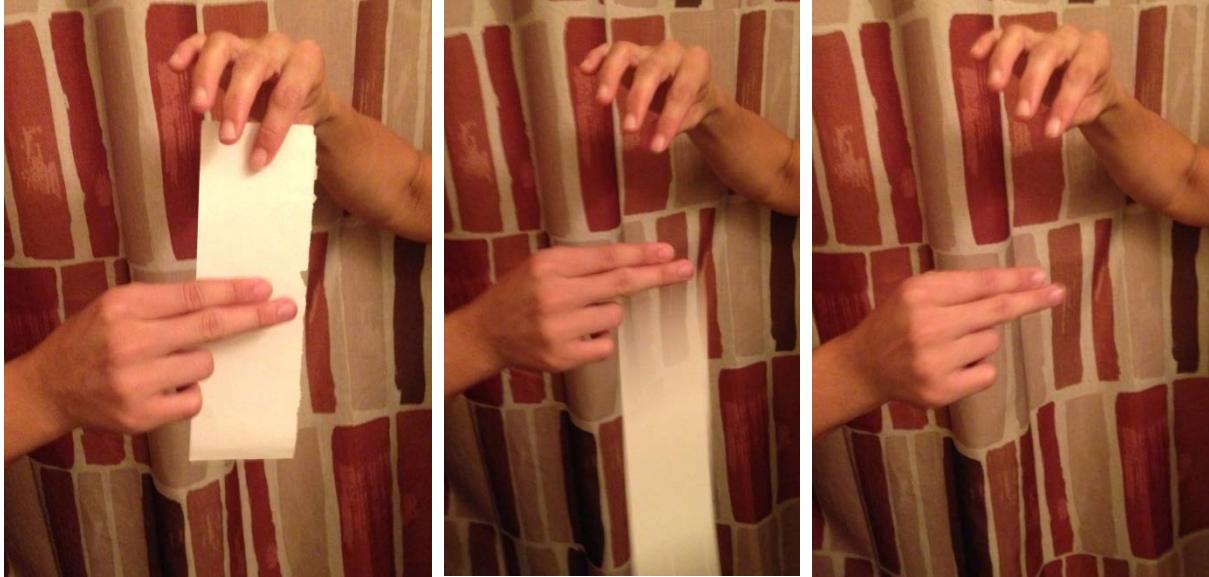
If the answer is no, here is why! Our brain uses image processing to determine when your partner let go of the paper and then sends signals to your hand for your fingers to catch it. However, your system has a delay between when your brain sends the signal and when your muscles act. That delay is long enough to allow the paper to slip past your fingers. The whole process from "seeing" the paper falling to "acting" takes time. There is minimum time that we cannot reduce. The process is faster than what we can handle. We wish we had a shorter processing time.

2.5.2. Moving Pen

Take any pen and hold it upward from the tip. Keep the pen in front of you and move your head side to side while continuing to fixate on the pen. Even if you are moving your head fast you can still clearly see the pen while your head and eyes are moving.

Now, keep your head still and move the pen in front of you from side to side and follow it with your eyes. Did you notice that at some point (at a certain moving pen frequency) you can't clearly follow the motion of the pen? The reason is that your brain undergoes additional image processing when the pen is moving, and this creates a delay in the system, and a limit to how fast you can process and act (it shows an upper limit of the frequency that can be handled).

Source: https://ryanhollingercritic.wordpress.com/2014/10/08/presentation-on-lighting-and-look-development
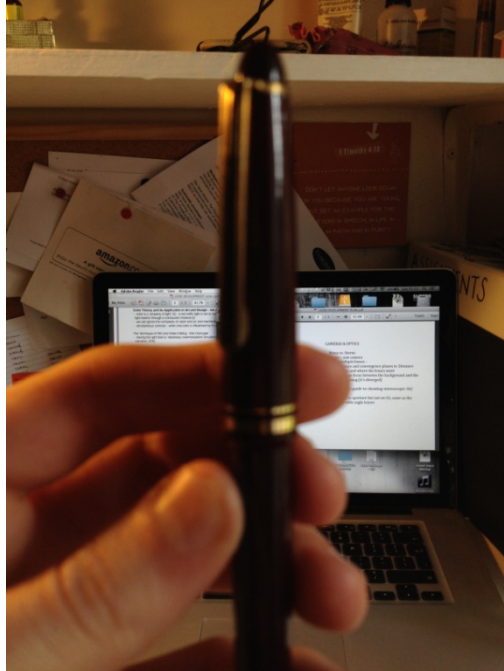
2.6. Did You Know's

The following examples provide interesting facts that relate to signal processing while also capturing the students' attention. The examples range from computers to music instruments. These examples cover time-domain sampling while one example covers sampling in another domain.

2.6.1. Flashing Light Bulbs

Did you know, the fluorescent light bulbs in your home are flashing on and off very fast? In fact, in the US these light bulbs flash on and off about 120 times per second. This is because the power is delivered at a frequency of 60 Hz but each cycle crosses zero twice making the light bulb turn on and off twice per cycle. Why can't we notice? Well, our "sampling rate" is too low for us to notice the flashing so we confuse it for a constant light source.

2.6.2. Octaves on Keyboard

As you may know, high pitch sounds are associated with relatively high audio frequencies (>1000 Hz) and low-pitch sounds are associated with low audio frequencies (<100 Hz). But did you know each key on the keyboard (including the black keys) represents a note and each note plays a frequency of approximately $2^{1/12} \approx 1.059$ times the frequency of the previous note. Each octave has twice the frequency of the previous octave (e.g. A-440 and A-220).

Therefore, the notes on the keyboard are considered to be on a logarithmic scale of frequency. The keyboard is an example of how the audible frequency spectrum, which is continuous, is sampled into certain frequencies. These frequencies are represented by each note on the keyboard.

Source: http://www.dspguide.com/ch22/2.htm
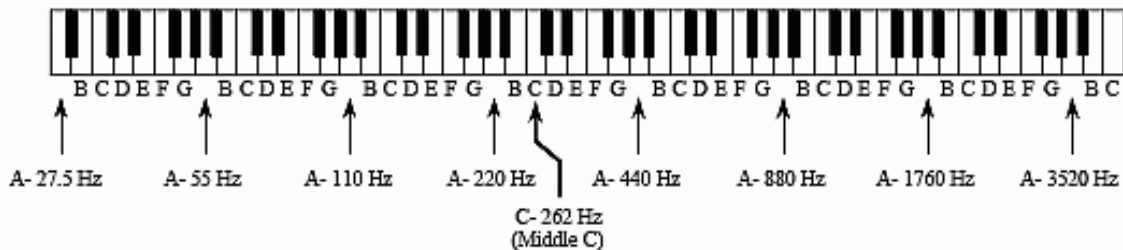
3. Assessment

The techniques and examples described in this paper were implemented in a lecture that was given to a Digital Signal Processing class taught by a co-author of this paper at Florida Atlantic University. This lecture was given towards the end of the semester since that is when most of the examples developed during this research were consolidated. In order to accurately gauge the effectiveness of this teaching technique, the students were encouraged to fill out an online questionnaire. The results of the questionnaire give insight on the receptiveness of the students to this method of learning. All of the results can be found in the appendix.

In the appendix, figures A.1-A.3 display the demographic breakdown of the students who participated. As seen in the figures, the group of students was ethnically diverse, most of them were males, and most were between the ages of 21 and 23.

One could easily observe from the figures in the appendix that the answers are typically skewed towards "strongly agree" or "strongly disagree" for the questions that ask about the student's opinion on different learning strategies. This may be analyzed numerically by considering the responses on a scale from 0 to 4. On this scale, zero represents "strongly disagree," two represents "neutral," and four represents "strongly agree." Using this system, the feedback given by the students could be quantified for each question. One of the questions was, "I feel that visualizing DSP concepts is important" (Figure 3.1). The average response for this question was 3.74, showing that the students felt strongly about visualizing the concepts they learned in the digital signal processing class. The feedback to this question supports the idea that student's in today's era prefer learning through visual techniques.
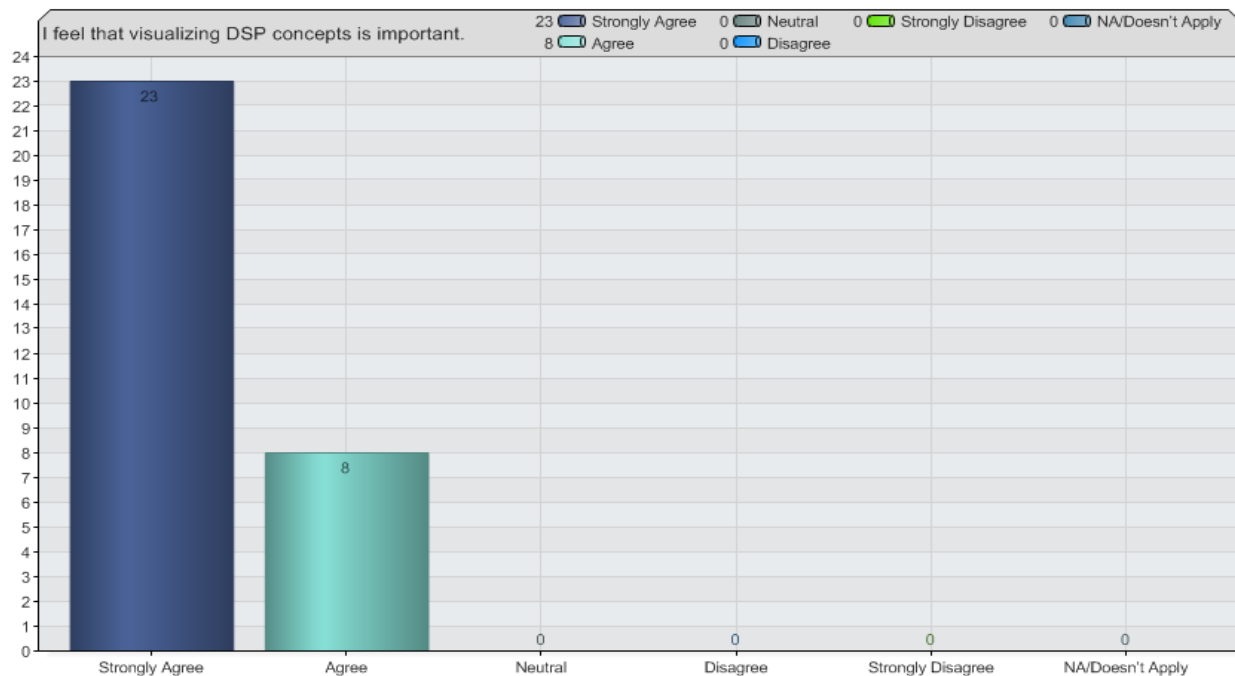
Figure 3.1: Student feedback on importance of visualizing DSP

An additional question of particular importance was the way students felt about using visual examples like the ones highlighted in this paper to introduce concepts in digital signal processing. In the question, "I prefer to be introduced to a concept in DSP via visual examples" (Figure 3.2), the average response was 3.52. This result provides further support to the idea that using visual techniques to introduce concepts is an effective method for helping students gain a better understanding of the concepts taught.
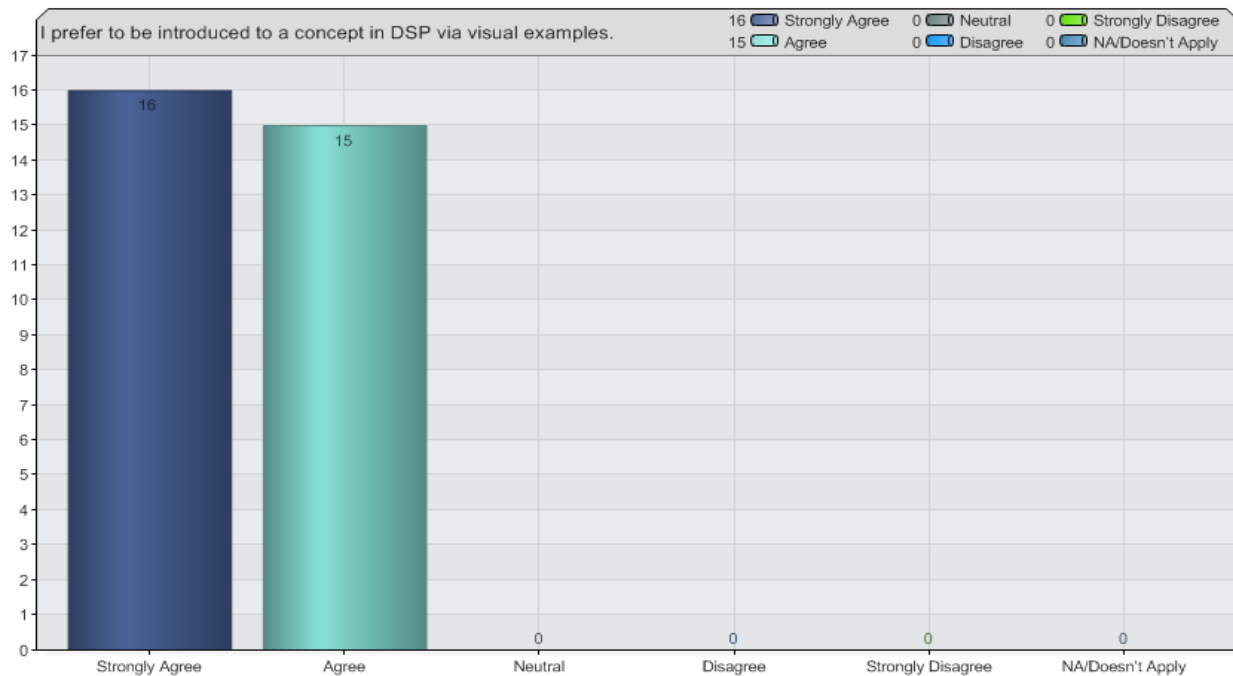
Figure 3.2: Student feedback on importance of being introduced to DSP concepts through visual examples

The responses of the students to the different questions provide valuable insight to which learning strategies they prefer. Additional feedback was given in the form of comments; an option given to the student on the questionnaire. Overall the students gave positive feedback about the presentation and gave additional ideas. Below are a few of the comments given by the students in the questionnaire.

It was very nice presentation in a simple way to understand the concept of some DSP material. It would be nice if it the students can be presented with some kind of real life implementation of the theory and calculation that we have done so far in the course.

Very good presentation, I hope all the EE classes are taught this way.

Great job on the presentation, very helpful in tying it all together. Having this kind of broad overview may be helpful in the beginning of the course as well.

The visuals/activities might help students when they're presented before the math/etc. I think it will be a great addition to teaching students DSP.

I enjoyed the presentation and I believe that these examples really help the student quickly grasp on to the concepts that are introduced in class. It would have been nice to have some of these examples shown in class side by side with some of the theoretical concepts taught in the lecture.

The positive reactions to this method of presenting information implies that it is effective and therefore worth researching more.

4. Conclusion and Future Work

Learning styles are different from person to person. An individual's learning style can change over time based on previous experiences and society around them. Advances in technology have changed the way people find solutions to problems. Similarly, these technologies have the ability to change the way people learn. With the popularity of the internet, it can be expected that learning strategies will continue to shift towards visual ones.

In the context of engineering education, teaching many of the concepts are especially difficult. This is because with all of the decades of innovation and research the information has built up into an extensive amount. Additionally, the internet makes most of this information readily available to anyone. So there is an overwhelming amount of information a student in engineering can learn. This can become quite intimidating when attempting to learn the fundamentals of so many fields within an engineering discipline.

In order for students to overcome these challenges it is essential that instructors adjust their teaching styles accordingly. Providing visual and intuitive examples to introduce topics in a subject within engineering could be quite helpful. This was demonstrated by applying these methods to digital signal processing, an important course in the standard electrical engineering curriculum.

This area of research is promising since there are so many more examples to create and analysis to do. The development of a more elaborate form of assessing the improvement of students before and after being presented with visual examples to introduce topics may reinforce the effectiveness of the techniques covered in this paper. Additionally, these techniques should be tested on different courses in engineering. Ideally, this method could be fine-tuned to be just right for the average learner and be expanded for all courses within engineering.

5. References

[1] Gangwer, Timothy (2009) *Visual Impact, Visual Teaching: Using Images to Strengthen Learning* 2nd ed. Corwin Press, CA.

[2] DeWitt, Tyler (2013) "TED Talks: Hey Science Teachers – Make it Fun," Retrieved from http://www.ted.com/talks/tyler_dewitt_hey_science_teachers_make_it_fun.html

[3] D. Raviv, G. Roskovich (2014) "An Intuitive Approach to Teaching Key Concepts in Control Systems" in Proceedings of the ASEE Conference, Indianapolis, IN, USA, June15-18, no. 9179
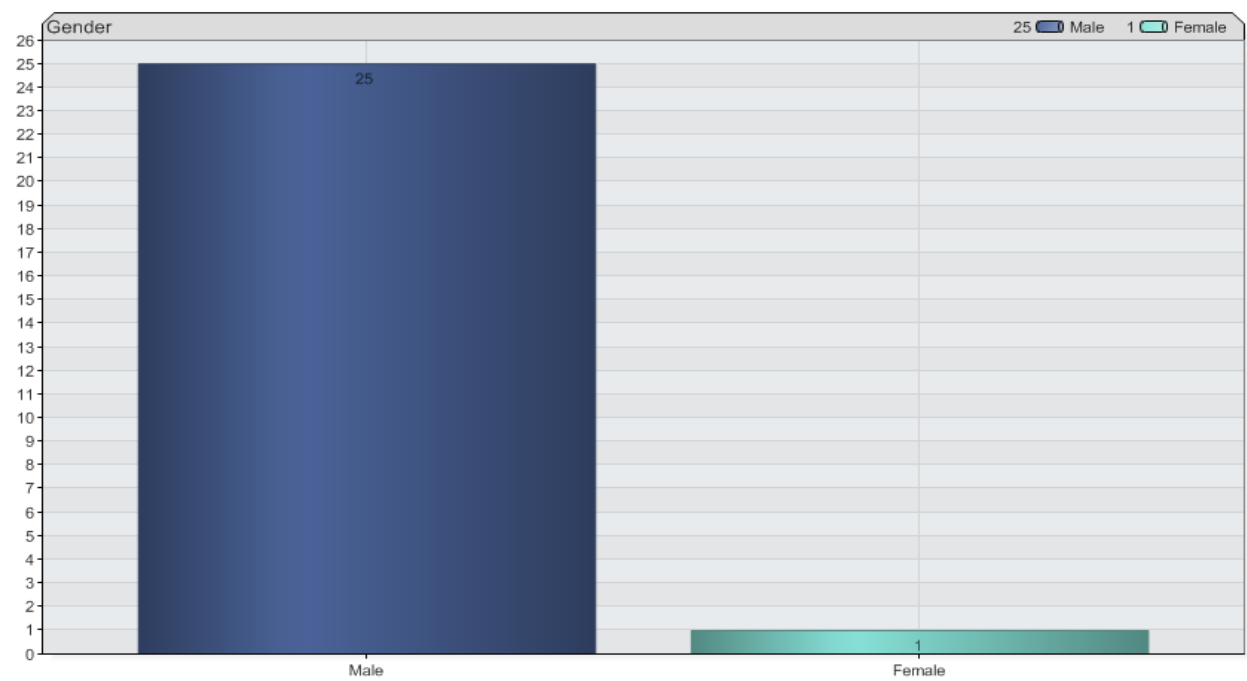
[4] http://electronics.howstuffworks.com/digital-versus-analog1.htm

Appendix

Figure A.1: Gender Distribution
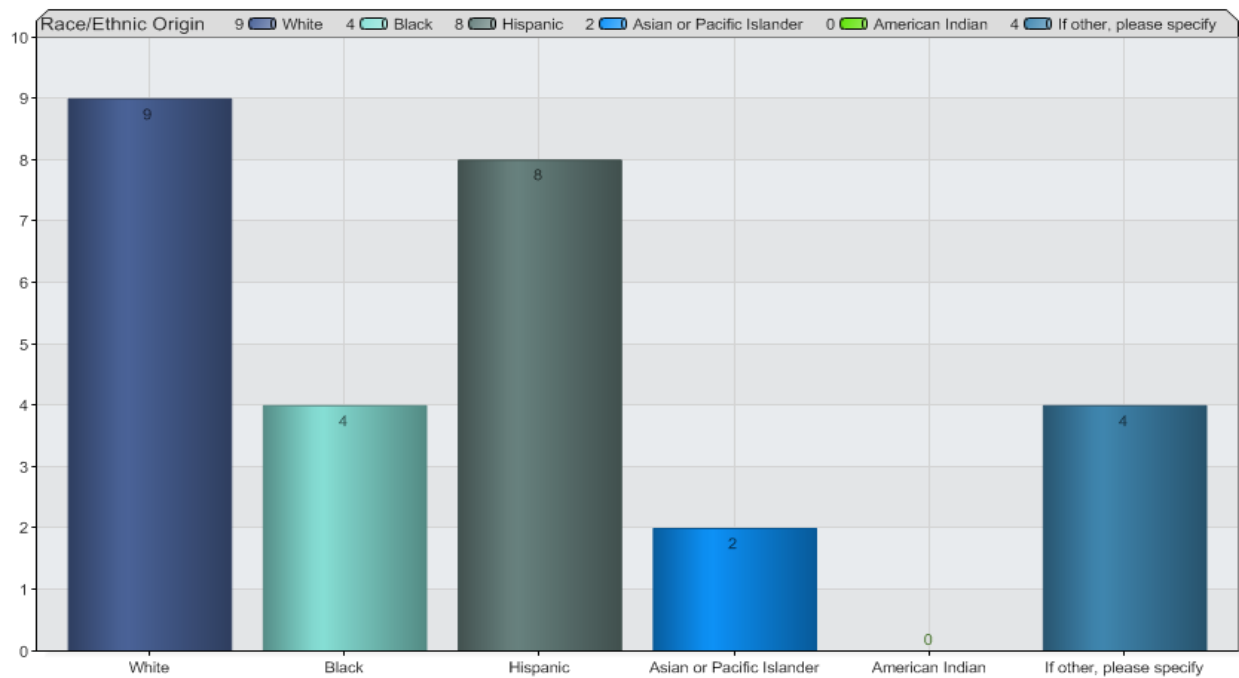
Figure A.2: Ethnic Distribution
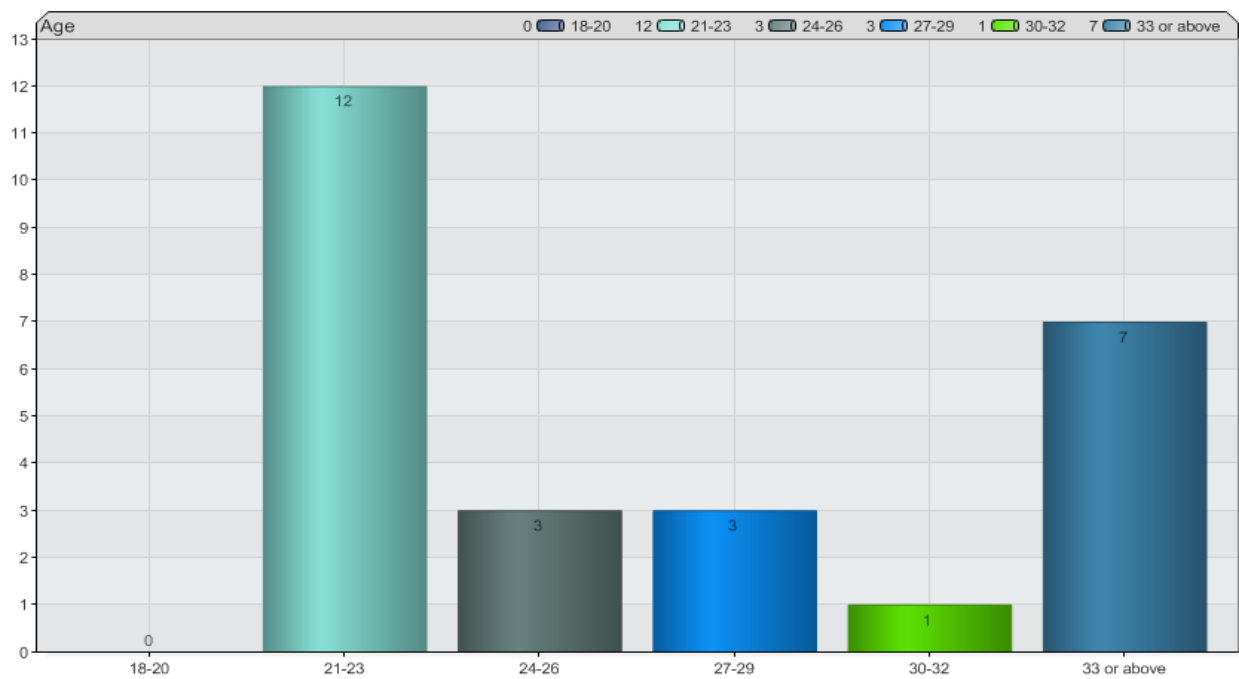
Figure A.3: Age Distribution
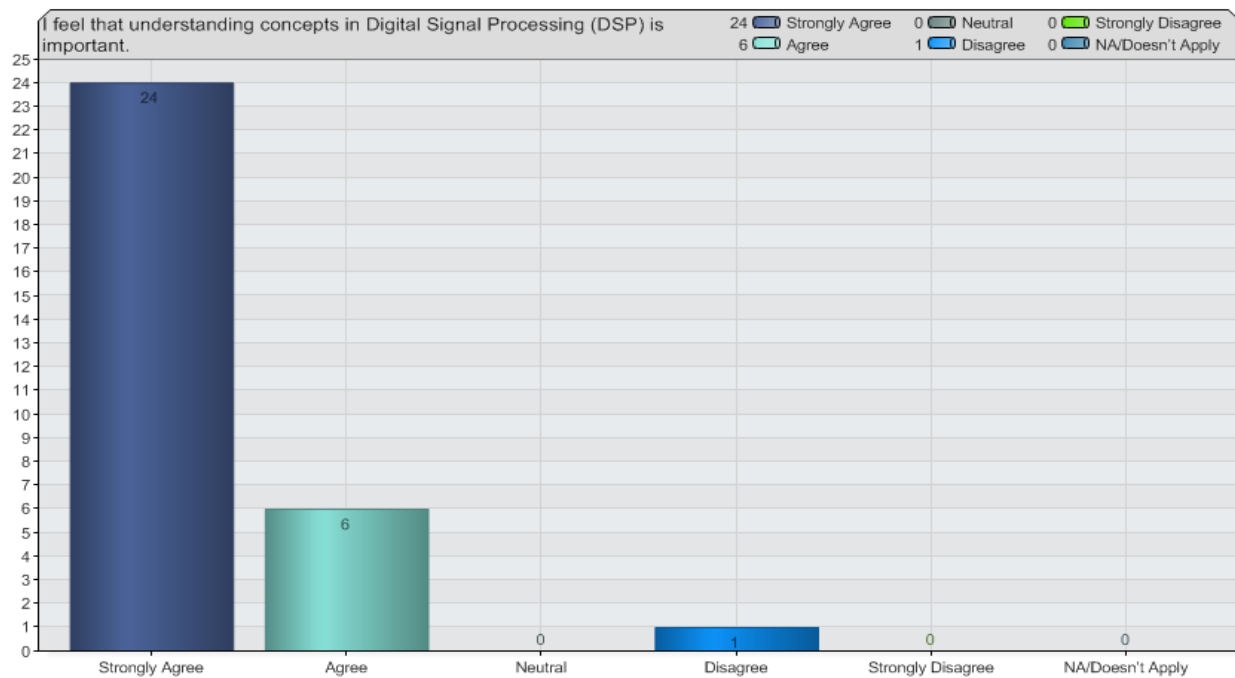
Figure A.4: Student feedback on importance of understanding DSP concepts
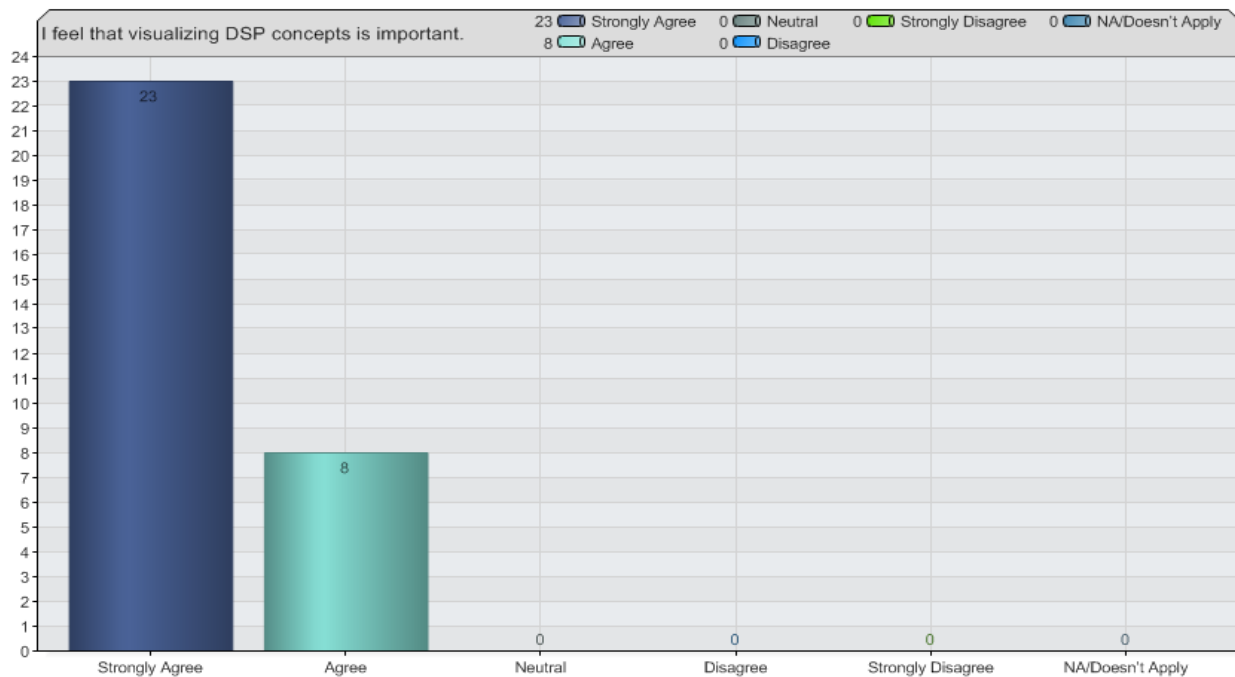
Figure A.5: Student feedback on importance of visualizing DSP
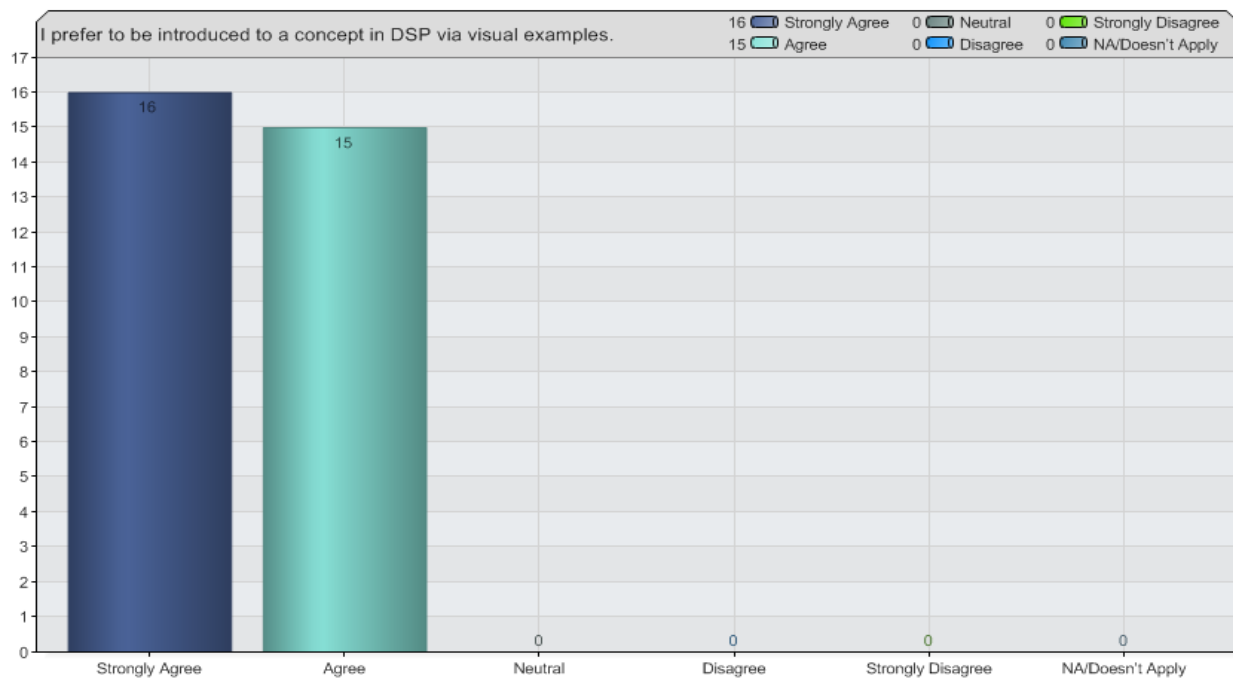
Figure A.6: Student feedback on importance of being introduced to DSP concepts through visual examples
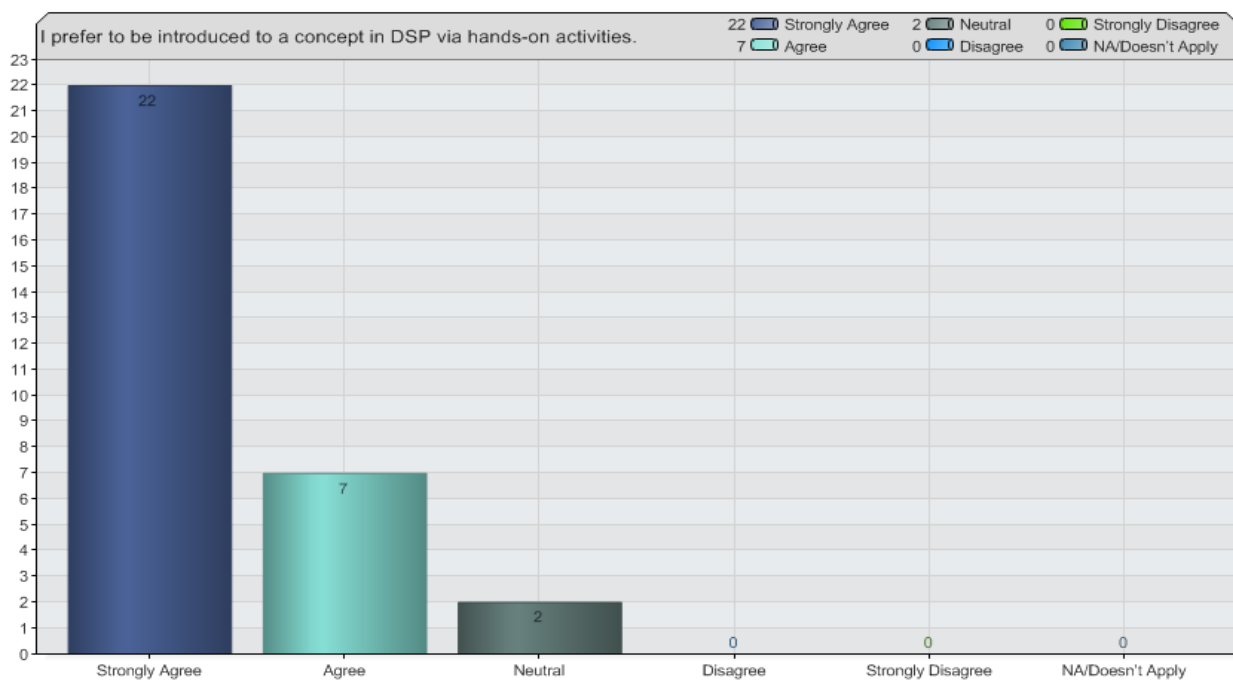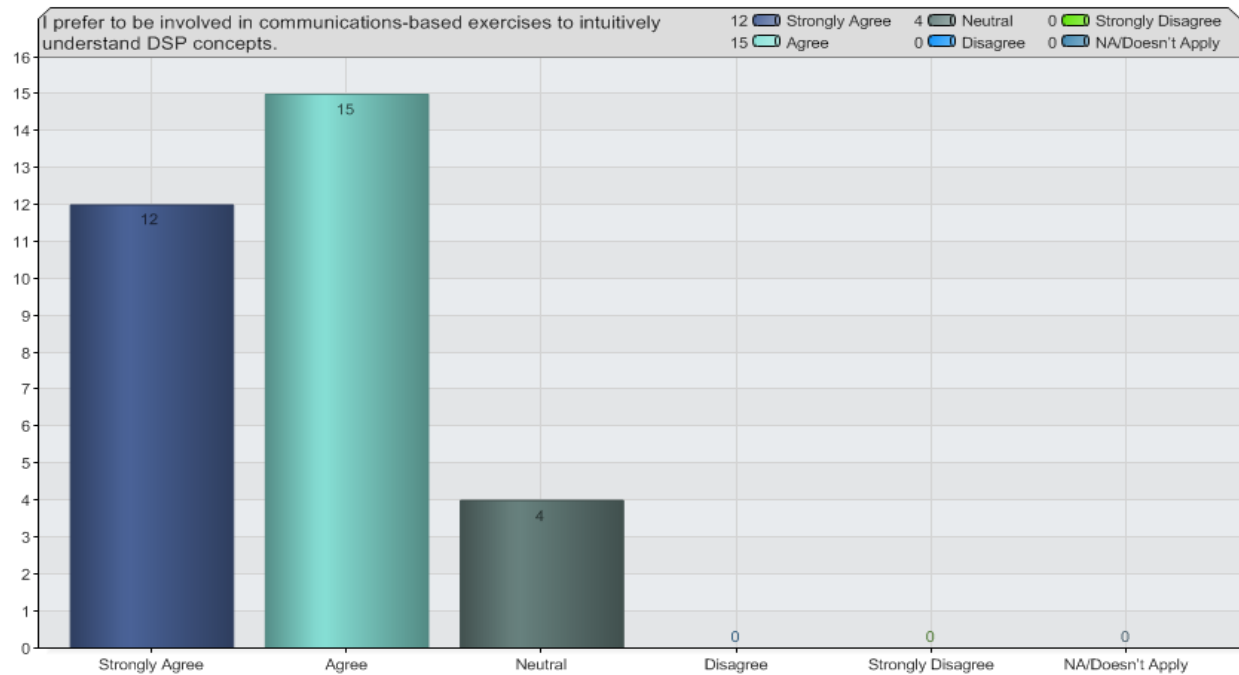
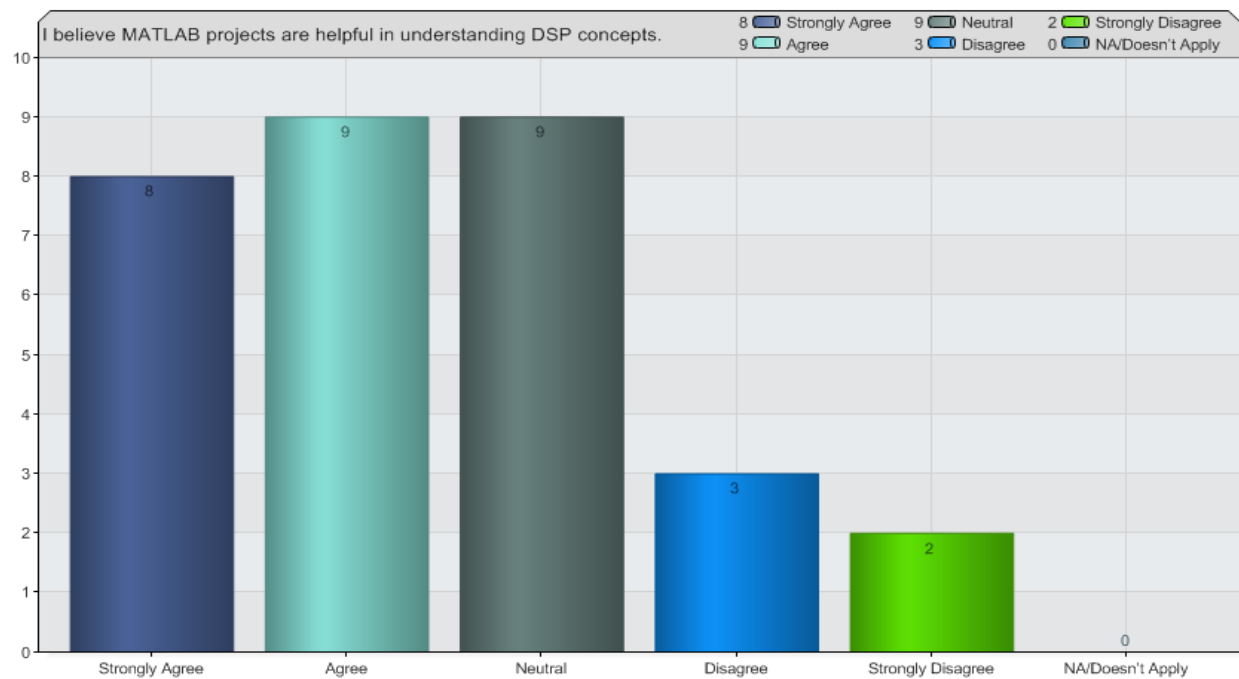**Figure A.8:** Student feedback on importance of using communications-based exercises to learn DSP concepts

Figure A.9: Student feedback on using MATLAB activities to reinforce DSP concepts
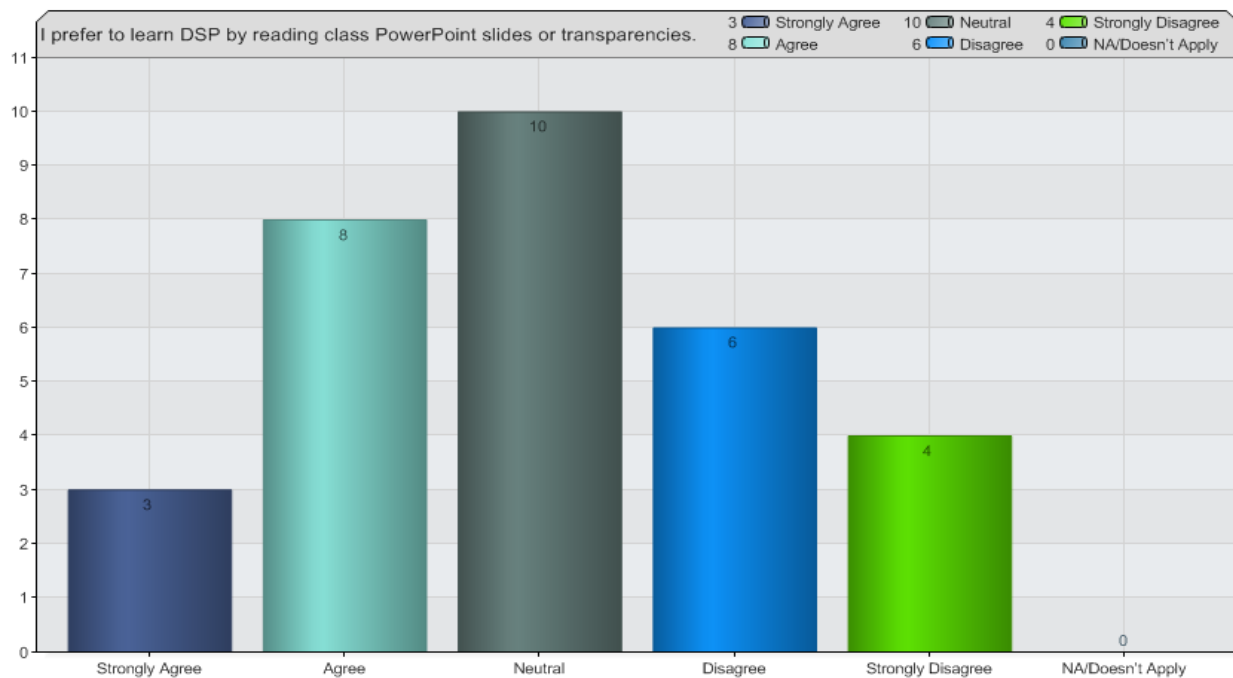
Figure A.10: Student feedback on learning DSP through PowerPoint presentations
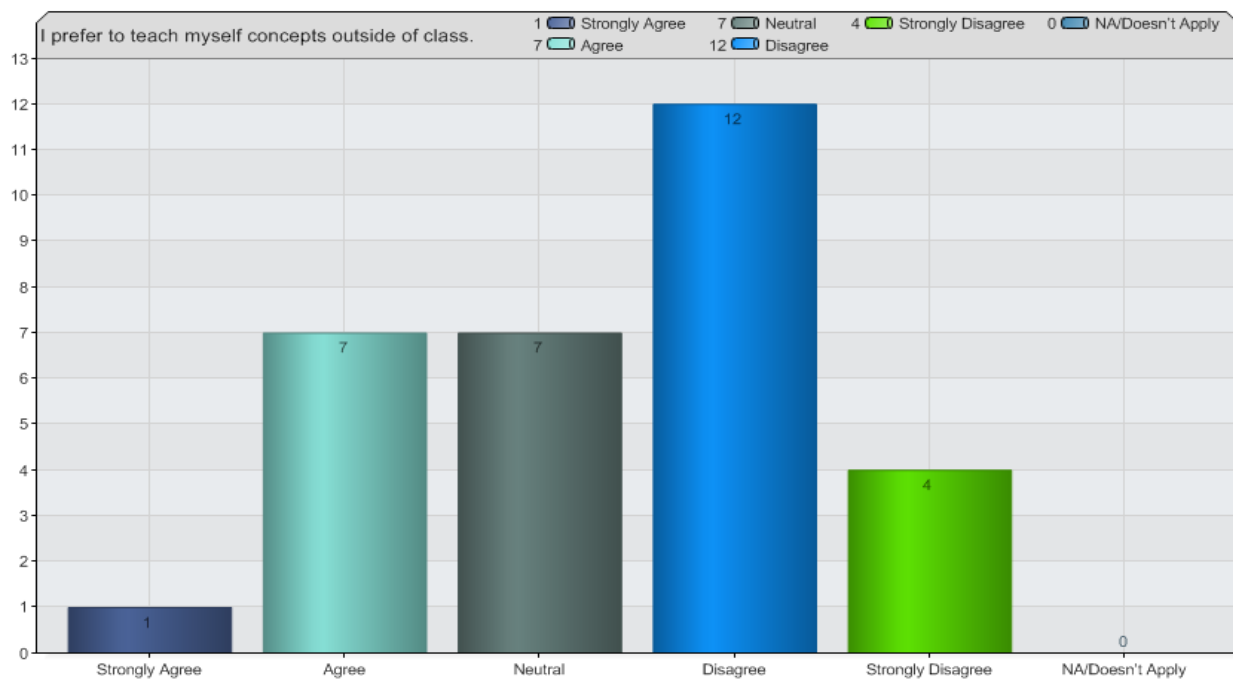

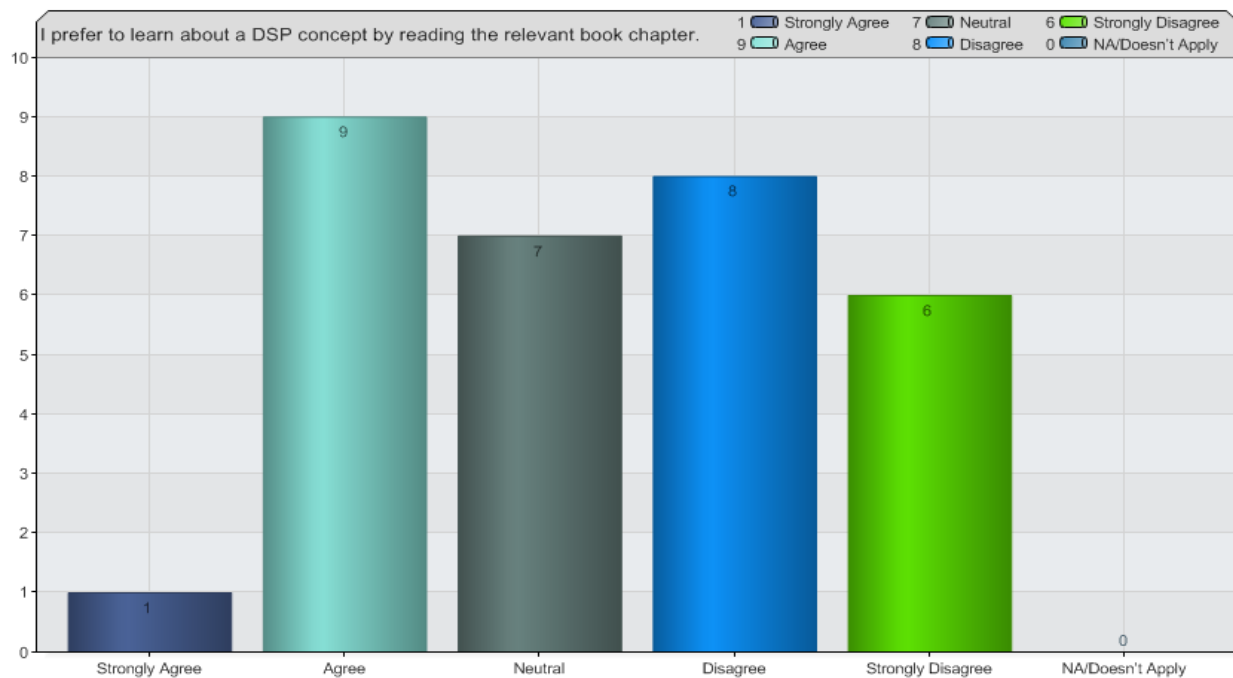**Figure A.11:** Student feedback on learning DSP outside of class

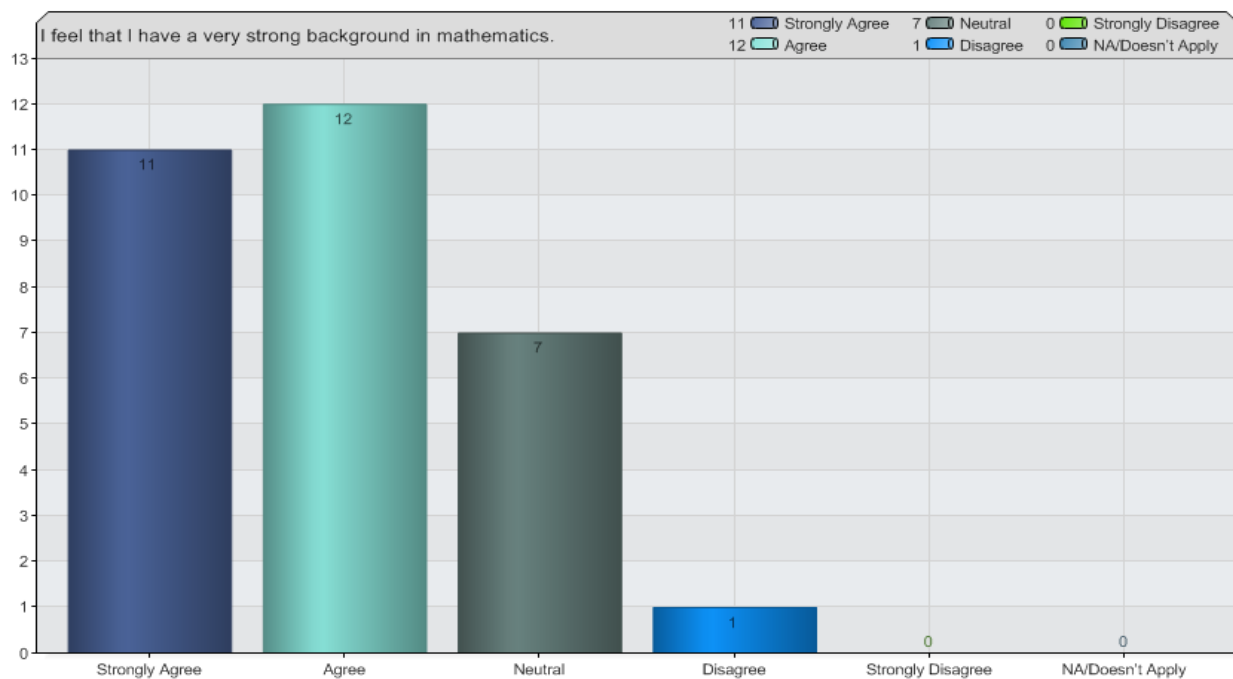**Figure A.12:** Student feedback on learning DSP by reading the relevant chapter in the book

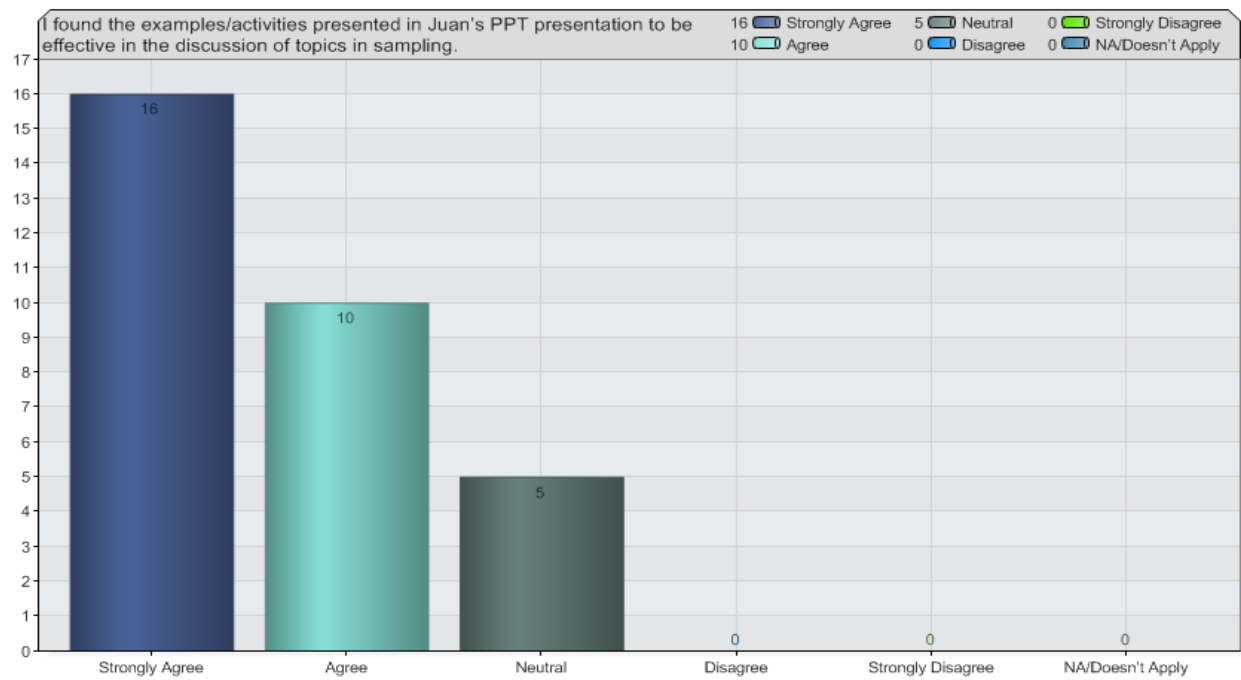**Figure A.13:** Student competencies in mathematics

Figure A.14: Student feedback on presentation given in the DSP class