THE USAGE OF AUGMENTED REALITY FOR AN INSTRUCTIONAL TASK

by

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To Christopher, for all of the time and memories that were sacrificed during the pursuit of my degree.

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LIST OF ABBREVIATIONS

AD2	Analog Discovery 2
AR	Augmented Reality
DEC	Digital Equipment Corporation
EV	Engineering Village
FCA	Fiat Chrysler Automobiles
HMD	Head Mounted Display
HUD	Heads-Up Display
JIT	Just-In-Time
SMED	Single Minute Exchange of Die
SoET	School of Engineering Technology
SUS	System Usability Scale
TPS	Toyota Production System

GLOSSARY

Industry 4.0 – The fourth Industrial Revolution that focuses on the integration of smart factories. The smart factories utilize a virtual cloud and smart technologies that connects the company's operations and company information in real time (Tortorella & Fettermann, 2018).

Likert Scale – "Forced-choice questions, where a statement is made and the respondent then indicates the degree of agreement or disagreement with the statement on a 5 (or 7) point scale" (Brooke, 1996, p. 191).

Just-In-Time – A production system that focuses on items being produced or delivered exactly when needed in regards to the customers demand (Womack & Jones, 2003).

Muda – Waste; any human activity that utilizes resources and does not add value to the process (Womack & Jones, 2003).

Poka-yoke – Mistake-proofing; the act of developing a device or procedure with the intent of alleviating defects during manufacturing (Womack & Jones, 2003).

Red Tag – A FCA indication that a gear is out of specification and Reishauer machining parameters need to be adjusted accordingly (Price, Mcdonald, & Ward, 2019).

ABSTRACT

Approximately 60% of lean manufacturing systems result in failure (Pearce & Pons, 2019). The failures are attributed to a lack of understanding of lean principles and a lack of commitment by employees (Almanei, Salonitis, & Tsinopoulos, 2018). The study hypothesized that incorporating augmented reality (AR) into the processes, would improve the overall success rate. An AR proof of concept was conducted using the Toshiba dynaEdge AR100 (Dynabook, 2019). The question that guided the proof of concept was, "how did instructional task times compare between AR instruction's and paper instruction's?" The literature review provided findings that the incorporation of AR contributing to a 33% decrease in fabrication cycle times (Segovia et al., 2015). The literature review also provided findings that AR incorporation worked best for complex assembly tasks (Capozzi, Lorizzo, Modoni, & Sacco, 2014). The study utilized 20 subjects, which were split evenly into two groups for each set of instructions. The 20 individuals were timed, and the data was analyzed using a two-sample t-test and a Cohen's d effect size analysis. The AR system's perceived usability was also analyzed through the use of a system usability scale (SUS). The study's findings for the t-test and the effect size analysis did not support the previously stated hypothesis. However, the AR system was determined to be useful, based off of the SUS findings. The study provides future researchers a starting point for AR related studies and a understanding of what to avoid.

Keywords: augmented reality, lean manufacturing, instructional task, system usability scale

CHAPTER 1. INTRODUCTION

The COVID-19 pandemic has led to alterations of this study (Wang, Horby, Hayden, & Gao, 2020). The study was originally focused around the Fiat Chrysler Automobile (FCA) transmission gear process. The augmented reality (AR) system was set to be implemented at the FCA transmission facility in Kokomo, Indiana. The AR system was going to be of use during operational shut downs that were a result of a gear being *red tagged*. Due to the pandemic affecting access to the FCA facility, the study switched to an AR proof of concept. The proof of concept was conducted to verify that AR contributes to a reduction in task times.

Augmented reality (AR) provides hands free instructions in the form of three-dimensional object overlap, word documents, pictures, and videos (Kipper & Rampolla, 2012). The AR environment is portrayed through a Heads-up display (HUD), head mounted display (HMD), mobile device or computer (Kipper & Rampolla, 2012). The three-dimensional overlap of objects provides the user with the proper orientation of an object during an assembly process. The operators are able to work along side problems in real time through the use of videos and pictures. The videos are live or recorded, with an experienced individual from the desired industry.

The practices and principles of lean reduce and eliminate waste in production systems. Lean principles are implemented in companies across the world, such as automotive companies Toyota and Fiat Chrysler. The worldwide acceptance of lean principles exposes problems and growth opportunities for the lean research field. The problem the study addresses is the percentage of failed lean production systems.

1.1 The Problem and Significance

According to Pearce and Pons (2019), 60% of lean production implementations result in failure. The lean implementation failures contribute to a decrease in organizational profits and a decrease in the lean adoption rate (Bhasin, 2013). Lean success can be achieved through immersive reality technologies, while enhancing the interoperability of the immersive reality system (Capozzi et al., 2014). Determining the success of a solution is contingent upon a time savings analysis and a usability test analysis. The study will align with the National Academy of Engineering's global grand challenge of enhancing virtual reality (NAE, 2019).

1.2 The Purpose

The purpose of the study was to determine how AR affects the down time and part production in a lean production system. Lean production is an established field, while *Industry 4.0* and its components (e.g. AR) are a developing field (Yeen Gavin Lai, Hoong Wong, Halim, Lu, & Siang Kang, 2019). Industry 4.0 began in 2012 by the German government (Y. Yin, Stecke, & Li, 2018), which allowed the conduction of original research, while building on the preexisting lean frameworks. Capozzi et al. (2014) states that AR can improve the production performance, especially in systems that involve human operators.

1.3 The Scope

The study focused on the utilization of the Toshiba dynaEdge AR100 AR system (Dynabook, 2019). The AR utilization aimed to achieve a decrease in instructional task times. The AR system was utilized in assembling the Analog Discovery 2 (AD2) USB oscilloscope (Digilent, 2020). The AD2 was used as an assembly kit to provide a comparison of AR instruction's and paper instruction's. The study utilized AR as an instructional and educational tool, providing the users with the knowledge to assemble the AD2 kit.

1.4 Research Questions

The research question that guided the study is below:

- How did instructional task times compare between AR instruction's and paper instruction's?

1.5 Assumptions

The study consisted of the following assumptions:

- The subjects completed the tasks at normal working pace and thoroughly read all instructions.
- The subjects had not used the Analog Discovery 2 USB oscilloscope before.
- The subjects were able to understand how to toggle through the AR instructions on the first use.

1.6 Delimitations

The study consisted of the following delimitation:

- The study was only conducted with Purdue University students that were enrolled in the School of Engineering Technology (SoET).

1.7 Limitations

The study consisted of the following limitations:

- The study was based around 20 SoET students at Purdue University.
- The study was conducted in spaces that met Purdue University's COVID-19 Standard Operating Procedures.

1.8 Summary

Chapter One provided an introduction into the study. The chapter covered the problem statement, purpose, scope, research questions, assumptions, limitations and the delimitation of the study. The lean, automotive and AR fields consist of overlap, which is covered in Chapter Two.

CHAPTER 2. REVIEW OF LITERATURE

Chapter Two covered literature that pertained to the study. The literature review consisted of the following:

- The methodology for finding relevant literature for the study.
- The overlap between lean principles, the automotive industry and augmented reality.
- The findings pertaining to the methodology of case studies and the system usability scale (SUS).

The lean, automotive and AR segments contained literature within a 10 year time period, since the fields consisted of developing research. The case study and SUS segments contained literature within a 30 year time period, due to the use of seminal documents.

2.1 Methodology of Review

The methodology for the study's literature review was based around the study's problem, purpose and focus. The problem being the 60% fail rate of lean production implementations (Pearce & Pons, 2019). The purpose being to determine how the utilization of AR affects the idle time and part production in a lean production system. The focus being the automotive industry, due to the use of assembly processes. The literature review was conducted by combining key terms from the problem, purpose and focus through the use of Boolean search terms (i.e. AND, OR, NOT). The review used ”OR” to combine the synonymous terms, ”AND” to combine the antonymous terms and ”NOT” to exclude specific terms. The list of key terms and the key term synonyms are listed below:

1. Lean
    - Waste-less
2. Augmented Reality
    - Mixed Reality

- Mixed Augmented Reality
- AR
- MR
- MAR

3. Automotive
    - Auto
    - Auto Industry
    - Automotive Industry
4. Production
    - Manufacturing
    - Assembly

The literature search was conducted through the *Engineering Village* (EV) and *IEEE Xplore* databases. The decision to use the EV and IEEE Xplore databases occurred after meeting with Purdue University Librarians, Sarah Huber and Megan Nelson. The EV and IEEE Xplore databases were accessed through the Purdue University library web portal. The content in EV and IEEE Xplore overlapped for engineering specific information, but varied for technology based information (e.g. AR). Engineering Village provided useful information for topics regarding lean manufacturing and the automotive industry. The IEEE Xplore database provided useful information for topics regarding AR. Both EV and IEEE Xplore contained limited information relating lean to AR.

The AR field is a developing industry and limited the useful literature when combined with lean production and the automotive industry. Due to the limits of the search, the literature review was separated into the following segments:

- Lean and Automotive
- Automotive and AR

- Lean and AR

The three segments of the literature review were analyzed to determine the overlap.

The SUS segment of the literature review was conducted differently than the previous segments. The masters thesis, *Usability of Real Time Data for Cold Chain Monitoring Systems* (Saxena, 2016), was utilized to find credible references for SUS. The authors of the references were then cross linked with the term ”System Usability Scale” in the *Purdue Library* search engine.

2.2 Findings Pertaining to the Lean and Automotive

The relationship between lean principles and the automotive industry can be traced back to the origins of lean. The Toyota Production System (TPS) founded lean and formed the principles of lean around *muda*, which is the Japanese term for waste. Womack and Jones (2003) refers to waste as any activity that utilizes resources and does not add value to the process. The seven forms of lean waste are below:

1. Waiting
2. Overproduction
3. Motion
4. Defects
5. Inventory
6. Transportation
7. Over-processing (Bidarra, Godina, Matias, & Azevedo, 2018)

Any type of wasteful activity in an automotive company can be categorized by one of the previously mentioned forms of lean waste.

Lean waste is identified through the five foundational principles of lean, which are as followed:

1. Define the value for the specific customer.
2. Define the value stream.
3. Establish flow for the value-added steps.
4. Allow the customer to pull products.
5. Strive for perfection in the specified process (Womack & Jones, 2003).

Each of the aforementioned principles work together to establish a well grounded lean implementation. Defining the value ensures a clear understanding of the value-added items, allowing a steady transition to the next steps. In-depth insight on the inner-workings of a process is provided through defining the value stream. Defining the value stream also allows the opportunity of discovering current and potential value-added and non-added items. The flow of the value stream provides continuous movement of the system and ensures that efficiency is optimized in every step. The customer pulling products allows for *Just-in-Time* (JIT) production to take place. Striving for perfection allows for continuous improvement and eliminates complacency in the production system. Womack and Jones (2003) state that transparency assists the strive for perfection, providing everyone involved with the same information and more insight on how to improve.

The automotive industry minimizes waste through the use of lean tools, such as SMED. The SMED concept focuses on the reduction of setup time and idle time by converting internal tasks to external tasks (Bidarra et al., 2018). Internal tasks being activities performed when the machine is stopped and external tasks being activities performed when the machine is running (Jebaraj Benjamin, Murugaiah, & Srikamaladevi Marathamuthu, 2013). According to Jebaraj Benjamin et al. (2013) the SMED concept consists of five steps, which are as followed:

1. Define the internal and external setup elements.
2. Separate the internal and the external setup elements.
3. Covert all possible internal elements into external elements.

4. Streamline the internal elements that are not converted into external elements.

5. Streamline the external elements.

The aforementioned steps are sequenced to provide an efficient layout for reducing the changeover time in a process. The process of reducing changeover time and converting the excess time into external tasks is illustrated in Figure 2.1. Observe how the changeover time, external task time, and total time are reduced throughout the SMED process illustration in Figure 2.1.

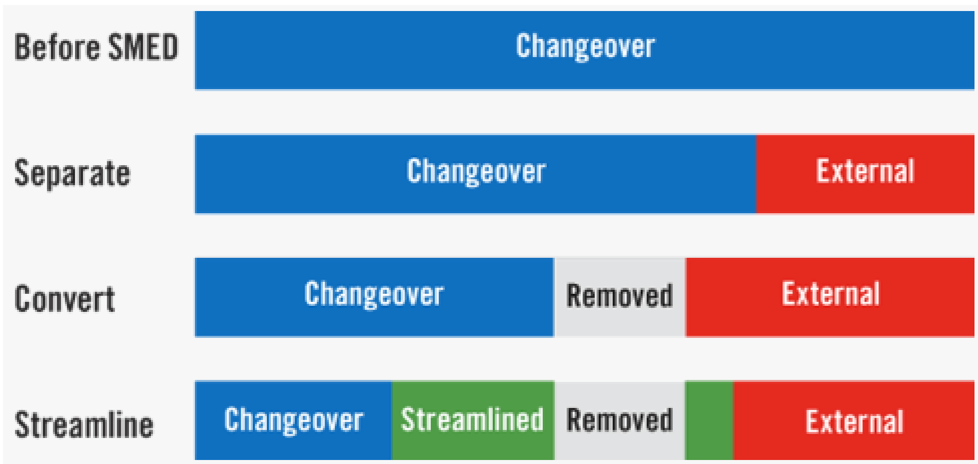

Figure 2.1. A display of how changeover time is reduced and converted into external activities (Vorne Industries, 2019).

2.3 Findings Pertaining to Automotive and AR

Augmented reality is being introduced into different industries, specifically the automotive industry. The automotive industry and AR industries are collaborating to improve the efficiency of automotive processes. Augmented reality provides hands free instructions in the form of three-dimensional object overlap, word documents, pictures, and videos (Kipper & Rampolla, 2012).

Gonzalez Mendivil, Naranjo Solis, and Rios (2013) state that the effectiveness of AR is best displayed in a complex task with a list of steps (e.g. servicing machinery). The automotive industry uses complex machinery to generate gears, bushings, engine blocks, etc. Over time, the machinery generates defective parts as a result of normal machinery wear. The machinery components are then required to be replaced or adjusted, in order to stop the production of defective parts. The introduction of AR into the complex machinery maintenance will assist the operator in completing the task correctly.

According to Kostolani, Murin, and Kozak (2019), AR can improve the quality of the maintenance process and reduce human error in the automotive industry. Kostolani et al. (2019) utilized AR in an automotive maintenance setting to provide the operator with a hands free instruction list. The information provided by the AR system ensured that the operator performed the maintenance task efficiently and correctly. The amount of production stops were also found to reduce after the AR implementation (Kostolani et al., 2019). The reduction in the amount of production stops is attributed to the maintenance procedures that were conducted with the AR system. The regulated machine maintenance ensured that the machine parameters were up to par, allowing for a reduction in the unexpected production stops.

2.4 Findings Pertaining to Lean and AR

The relationship between lean production and AR is developing. Lean production and AR have been around since the 1900’s, but AR is experiencing technological advances that are leading to new developments. The developments consist of HUD’s, HMD’s and smartphones (Kipper & Rampolla, 2012). The aforementioned devices provided a display of the augmented reality that is applied to environments, such as production and manufacturing settings.

Capozzi et al. (2014) utilized lean manufacturing principles and AR technology to reduce production time for a sofa production company. Lean principles were used to minimize production waste (i.e. time) and the AR system was used to convey the lean information in real time. The lean principles that were utilized are the reduction of non-value added time, employee mistakes (i.e. *poka-yoke*), unnecessary motion and unnecessary transportation of goods (Capozzi et al., 2014). Capozzi et al. (2014)

determined that the AR and lean implementation lead to a reduction in the production time and recommends the implementation for human operations.

Segovia et al. (2015) utilized lean manufacturing principles and AR technology to reduce the time for fabrication and dimensional validation process's in a machine shop. Lean principles were used to reduce the fabrication and validation times and the AR was used to properly orient the work piece. Segovia et al. (2015) used the lean principles, JIT and SMED to reduce the overall time of the production system. The SMED application kept the machine setup time under 10 minutes and the JIT application optimized production material arrival time (Segovia et al., 2015). Segovia et al. (2015) compared the times of the machining process with AR and without AR. The time comparisons displays a 33% decrease in the cycle time when the AR system was used (Segovia et al., 2015).

The use of AR and lean principles reduce the production time in a manufacturing or production system. The AR and lean combination performs well in complex assembly (Capozzi et al., 2014) and in complex machinery manufacturing (Segovia et al., 2015).

2.5 Findings Pertaining to Case Study Methodology

The seminal text by Robert K. Yin, *Case Study Research: Design and Methods*, was referenced for the case study methodology. The aforementioned text verified the need for a case study, defined the design method and defined the data collection method. R. Yin (2003) states that the following three conditions must be considered to determine if a case study is appropriate for the proposed research:

- The type of research questions being ask
- The control over behavioral events
- The focus on contemporary events as opposed to historical events.

Research questions that ask ”how” or ”why” are exploratory in nature and align with operations that need to be tracked over time (e.g. How does AR affect machine down time?) (R. Yin, 2003). The control over behavioral events refers to the observed behaviors in a study being absent of manipulation or interference from the observer (R. Yin, 2003). Focusing on contemporary events allows for the gathering of first hand information, where histories focuses on previous documentation and artifacts (R. Yin, 2003). The initial conditions for starting a case study ensures that the research will consist of current unbiased observations. The designing of a case study is conducted after the case study approach is deemed appropriate.

The designing phase contributes to the overall strength of a case study. The research design requires knowledge of case study framework and general ideas regarding the case to be studied. R. Yin (2003) states that the following five conditions are important for the research design:

1. The study's questions
2. The study's propositions (if any)
3. The units of analysis
4. The logic connecting the propositions and data
5. The method for analyzing the findings

The type of questions that are posed by a study reflect the nature and the substance of the study. The beginning of Section 2.5 covers the appropriate type of research questions for case studies. The propositions of a study identify the areas in a study that are of focus (R. Yin, 2003). Identifying propositions allows for the researcher to state theories and gain a sense of direction for the study. The unit of analysis defines the case that is to be studied (R. Yin, 2003). The case can refer to individuals, settings, events, etc. The unit of analysis relates back to the the structure of the research questions (R. Yin, 2003). The main concept in the research questions ultimately determines the unit of analysis. Connecting the data and the propositions refers to determining the pattern (if any) between the theory and the data/observations (R. Yin, 2003). Determining the pattern will verify or deny the researchers theories, in regards to the reasoning behind the research questions. The method for analyzing the study's findings is contingent upon the type of study. The purpose of the analysis method is to verify the findings pertaining to the pattern correlation (R. Yin, 2003).

Case studies are challenged and criticized, stating that there is a lack of quantification and rigor (R. Yin, 2003). According to R. Yin (2003), the following three test must be utilized to determine the quality of a research design:

- construct validity
- external validity
- reliability

Sekaran and Bougie (2016) utilizes the previously mentioned conditions as well, to test attest to the rigor of a study. Construct validity determines how the results of the study align with the theoretical framework of case studies (Sekaran & Bougie, 2016). The external validity of a case study refers to the study's findings being applicable to different settings (Sekaran & Bougie, 2016). Reliability refers to the study being reflective of the foundational case study approaches (Sekaran & Bougie, 2016).

The data of the case study derives from six sources. According to R. Yin (2003), the six sources of evidence are below:

1. Documentation
2. Archival Records
3. Interviews
4. Direct Observations
5. Participant-observation
6. Physical Artifacts

Documentation refers to recorded information that is relevant to the study (R. Yin, 2003). Documentation evidence consists of letters, agendas, proposals, etc. Archival records refers to computer files and records of an organization (R. Yin, 2003). Archival records consists of service records, maps, organizational charts, etc. Interviews refer to a guided conversation between the observer and the informant (R. Yin, 2003). During an interview the researcher compiles pertinent questions to the study, as well as conversational questions to establish a casual conversation feel (R. Yin, 2003). Direct observations refers to the gathering of first hand information at the site of the case study (R. Yin, 2003). The direct observations are conducted at the factory floor, offices, meetings, etc. Participant-observations refers to the observer taking a role in the events of the study (R. Yin, 2003). R. Yin (2003) uses the example of the observer for a study residing in the neighborhood that is being studied. Physical artifacts refers to an object that is collected or observed during a site visit (R. Yin, 2003). A physical artifact consists of technological devices, a instrument, a work of art, etc (R. Yin, 2003).

2.6 Findings Pertaining to the System Usability Scale

Introducing technologies into a manufacturing system assists the operators by reducing the overall workload. However, the capabilities of the technology are irrelevant if the technology is not used. The use of a technology is determined through the SUS. According to Lewis (2018), the SUS assesses the perceived use of a system with a standard set of questions. The standardized questions allows for a quantitative method to be applied to the study through the use of a scoring system.

The SUS utilizes the *Likert scale* to apply quantitative values based off of the agreement or disagreement with a statement (Brooke, 1996). In regards to usability, Brooke (1996) focuses on the following measures:

- Effectiveness
- Efficiency
- Satisfaction

Effectiveness refers to the operators ability to finish a task and the quality of the finished tasked, while using the proposed system (Brooke, 1996). Efficiency refers to the amount of effort put into completing the task with the proposed system (Brooke, 1996). Satisfaction refers to the operators personal response to using the proposed system

(Brooke, 1996). Figure 2.2 displays the original SUS, created by Brooke (1996) and Digital Equipment Corporation (DEC). Observe the use of a five point scale and 10 questions that alternate between a positive and negative tone in Figure 2.2.

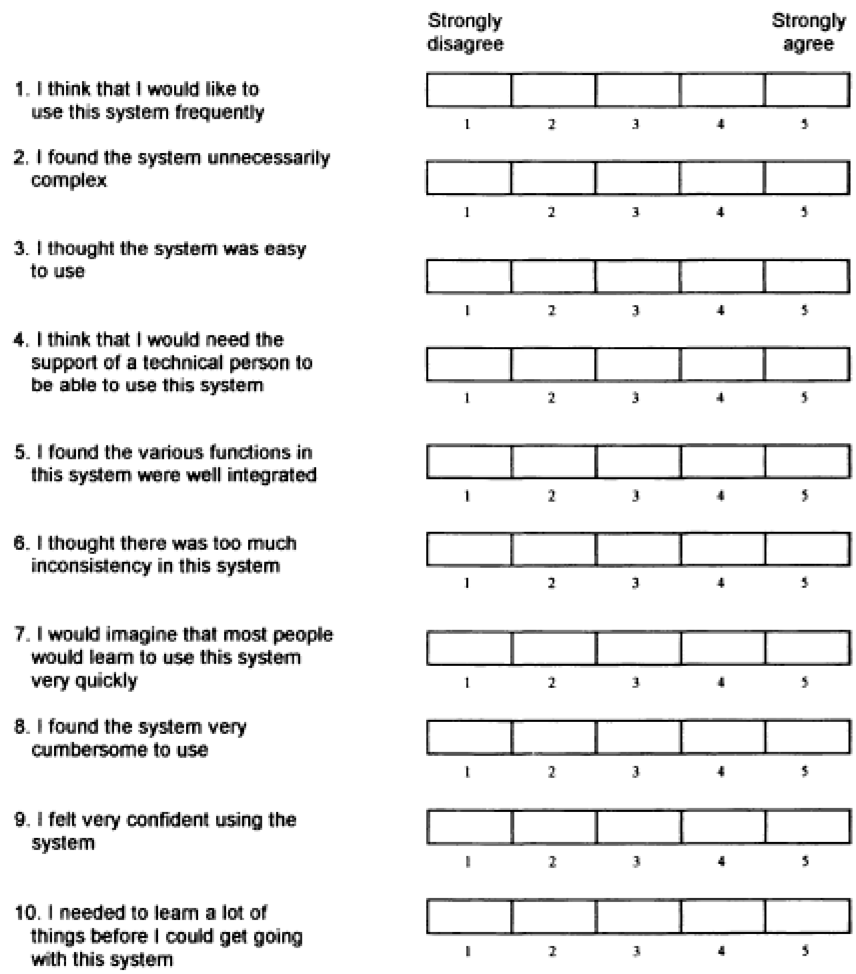

Figure 2.2. The Original System Usability Scale (Brooke, 1996)

According to Brooke (1996), the scoring for the SUS is calculated through the following steps:

1. Subtract 'one' from the values of the odd number questions (i.e. 1,3,5,7,9) and add the values together.

2. Subtract the values from even number questions (i.e. 2,4,6,8,10) from 'five' and add the values together.

3. Sum all of the current values and multiply by 2.5.

During scoring, if a value is not entered then 'three' should be assumed as the appropriate value. Lewis (2018) condenses the aforementioned steps into the following equation:

$$SUS = 2.5[20 + \sum(Q1, Q3, Q5, Q7, Q9) - \sum(Q2, Q4, Q6, Q8, Q10)] \qquad (2.1)$$

Qn = Corresponding Question Value (e.g. Q1 = Question 1)

The original SUS alternates between between a positive tone and negative tone for each question. The odd number questions have a positive tone and the even number questions have a negative tone. Brooke (1996) constructed the SUS with alternating tones to reduce response bias, which requires the participant to think about each question. Lewis (2018) states that the alternating tones cause mistakes and miscoding. Mistakes refers to the participant having trouble switching between the tones and miscoding referring to the researcher swapping the scores during calculations (Lewis, 2018).

The creation of a positive tone SUS was conducted by Sauro and Lewis (2011), which is displayed in Figure 2.3. Observe the similar setup to the original SUS, but the difference being that each question has a positive tone, in Figure 2.3. The positive SUS is recommended by Sauro and Lewis (2011) for researchers that are not currently invested in the original SUS.

	The System Usability Scale Positive Version		**Strongly Disagree** 1	2	3	4	**Strongly Agree** 5
1	I think that I would like to use the website frequently.		O	O	O	O	O
2	I found the website to be simple.		O	O	O	O	O
3	I thought the website was easy to use.		O	O	O	O	O
4	I think that I could use the website without the support of a technical person.		O	O	O	O	O
5	I found the various functions in the website were well integrated.		O	O	O	O	O
6	I thought there was a lot of consistency in the website.		O	O	O	O	O
7	I would imagine that most people would learn to use the website very quickly.		O	O	O	O	O
8	I found the website very intuitive.		O	O	O	O	O
9	I felt very confident using the website.		O	O	O	O	O
10	I could use the website without having to learn anything new.		O	O	O	O	O

Figure 2.3. The Positive System Usability Scale (Lewis, 2018)

The scoring for the positive SUS varies from the original SUS due to all of the questions having a positive tone. The scoring steps for the positive SUS are below:

1. Subtract one from all of the question values and add the values together.
2. Multiply the summed values by 2.5

The positive SUS scoring steps are condensed into the following equation:

$$SUS = 2.5[\sum_{n=1}^{10}(Q_n) - 10] \tag{2.2}$$

2.7 Summary

Chapter Two provided a review of the literature that is relevant to the study. The chapter covered findings related to the following:

- The methodology for finding relevant literature for the study.
- The overlap between lean principles, the automotive industry and augmented reality.
- The findings pertaining to the methodology of case studies and the system usability scale (SUS).

The literature review concluded that AR reduces the automotive and lean manufacturing times. The lean principles in an automotive setting allow for a time reduction, specifically with the application of the SMED concept. The addition of AR into the manufacturing environments ensures that the process is done correctly the first time, thus decreasing wasted time (Kostolani et al., 2019). The incorporation of lean training into the AR system allows for the operator to have minimal waste practices incorporated into work habits.

The findings pertaining to case studies concluded that the design of a study contributes to the rigor and validity that is displayed. The case study methodology by R. Yin (2003), provided specific conditions that are to be met to create a rigorous case study. The case study framework not only allows for a rigorous study, but also determines if the case study approach is appropriate.

The findings pertaining to the SUS concludes that a quantitative method is applicable to a qualitative study. The SUS allows for the perceived usability of a system to be determined based off of the operators subjective participation (Brooke, 1996). The SUS has modified versions that allow for a reduction in observer and participant error, specifically the positive SUS (Lewis, 2018). Overall,the SUS conducts an analysis that displays reliability and validity.

CHAPTER 3. RESEARCH METHODOLOGY

Chapter Three covered the research methodology for the study. The research methodology consisted of the research type, research design, the used hardware's and software's, the SUS, the and data collection. Please note that the proposed methodology for the study was altered due to the COVID-19 pandemic. The study originally contained information that was specific to the Fiat Chrysler Automobile (FCA) transmission gear process. All of the information that was directly related to a specific FCA process, has been removed.

3.1 Research Type

The study took an exploratory case study approach. The case study design and framework was based around the seminal text by Robert K. Yin, *Case Study Research: Design and Methods*. The conduction of a case study was based around the three conditions that are stated in Section 2.5. The research question that the study focused on is below:

- How did instructional task times compare between AR instruction's and paper instruction's?

The aforementioned questions met the first condition, which referred to the type of question being asked. R. Yin (2003) stated that the appropriate research questions for a case study asks ”how” or ”why”. The research questions asked ”how”, which allowed for an exploratory approach with the opportunity for the process to be tracked over time.

The second condition for determining the need of a case study referred to the control over behavioral events (R. Yin, 2003). The observer did not interfere or manipulate the study during observations. The observer informed the operators of the study and observations that took place, prior to the study being conducted. The observer kept a distance during observations, in order to allow for the tasks to be performed at normal operating conditions.

The third condition for determining the need of a case study referred to the focus on contemporary events instead of historical events (R. Yin, 2003). The study was based around a first time use of the AR system. The first time use of the AR system allowed for first hand information to be gathered and avoided only analyzing previous documentation.

3.2 Research Design

The research design provided the layout of the proposed study, starting with the beginning and working towards the end. Properly laying out the research design allowed for a robust and rigorous study to be conducted. The study utilized the five conditions that were mentioned in Section 2.5. The first condition being the type of questions that the study contained.

The study met the first condition through the use of ”how” type questions. The type of research questions being asked were previously mentioned in Sections 1.4 and 3.1. The ”how” type of research questions created an exploratory approach with ability to track the content of the question over time. R. Yin (2003) attested that ”how” and ”why” research questions define the exploratory nature of a study. The research question explored the correlation between the delivery of two types of instructions. The two types of instructions being AR instruction’s and paper instruction’s.

The second condition for research design referred to the propositions of the study, if any at all. The proposition was based around the research question of the study, allowing for the identification of the study’s direction (R. Yin, 2003). Also, allowed for the researcher to present a theory surrounding the components of the study. The researcher theorized that the AR instruction’s would take a shorter amount of time to complete than the paper instruction’s. The AR system allowed the user to have access to hands free instructions, thus minimizing the amount of overall movement. The minimization of movement allowed for more time to be spent focusing on the task at hand. Thus, reducing the amount of time required to complete a hands on task.

The third condition referred to the study’s unit of analysis. The unit of analysis referred back to the research question and defines the case that is studied (R. Yin, 2003).

The unit of analysis for the study was the time taken to complete a task. The amount of time for a task was the underlying link between the research questions. The excessive time was the form of waste that the study used to analyze the impact of the AR system. A decrease in excessive time contributed to more time being available to complete given tasks.

The fourth and fifth conditions switched the focus of the research design to the data analysis segment. The fourth condition referred to the link between the data and the propositions. The purpose of the fourth condition was to determine if a pattern exists between the theory and the data (R. Yin, 2003). The theory of the study revolved around the amount of time taken to complete a task with two forms of instructions. The collected data and the theory were linked through a visual time comparison. The average time for both sets of tasks, along with each individual data point, were graphed and compared. The comparison of the graphs determined if a pattern exist between the two sets of instructions. Thus, confirming or denying the previous theory that was stated in the second condition. The study also compared and analyzed the time data statistically in the fifth condition.

The fifth condition referred to the criteria for interpreting the findings of the study. The purpose of the fifth condition was to verify the conclusion of the pattern, from the fourth condition (R. Yin, 2003). The instruction's data set times were analyzed through a two-sample t-test and a Cohen's d effect size analysis. The instructional task data was entered into the statistical software, *JMP*, where the t-test and effect size analysis were then conducted (SAS Institute Inc., 2019).

The research design phase ensured that case study was appropriately laid out. The lay out of the research design contributed to the overall strength of the case study. According to R. Yin (2003), the research design phase ensured that the study addressed and did not stray away from the research question. Once the research design was in place, the design was judged for overall quality. There were two test that were used to determine the quality of the research design. The two test were construct validity and reliability (R. Yin, 2003).

3.2.1 Construct Validity

The purpose of the construct validity test was to specify a set of measures for the study of the instructional task completion times. R. Yin (2003) stated that the testing of construct validity requires the following two steps to be conducted:

1. Specify the tasks that are to be observed.
2. Verify that the measures of the times reflect the specified tasks that are to be observed.

After the two steps were covered, key informants reviewed the draft of the study (R. Yin, 2003).

The study observed the time of completion for one task with two different sets of instructions. The time was measured in minutes with the use of a stopwatch. The time was measured from the moment that the assembly kit was touched, until the subject raised their hand and said ”time.”

The construct validity test was enhanced through the use of Yin’s suggestion of having the study’s draft being reviewed by key informants. The key informants that reviewed the draft were the researcher’s committee members.

3.2.2 Reliability

The purpose of the reliability test was to minimize biases and errors by ensuring that the study is able to be repeated (R. Yin, 2003). The reliability test was addressed during the data collection aspect of the study. R. Yin (2003) suggested creating steps that were detailed and operational, while performing as if someone were constantly looking over the researcher’s shoulder.

The study ensured reliability through detailed documentation and following case study protocol. The detailed documentation allowed for the researcher to conduct the same case study over and over again. The results of repeated case studies are not important. The importance lies in repeated case studies being conducted in the same manner as the original. The case study protocol ensured that the researcher's case study focused on the proposed problem, in a rigorous manner.

3.3 Augmented Reality Hardware and Software

The study utilized the Toshiba dynaEdge AR100 hardware (Dynabook, 2019). The dynaEdge was an HMD that operated using the Toshiba dynaEdge DE-100 mini computing system (Dynabook, 2019). The dynaEdge assisted the subjects as an instructional tool. The dynaEdge was used as an instructional tool to assemble the Analog Discovery 2 (AD2) Oscilloscope kit that is discussed in Section 3.5 (Digilent, 2020). The AD2 assembly reflected the type of complex task that utilizes the effectiveness of AR systems, which is referred to in Section 2.3. The Toshiba dynaEdge is shown below in Figure 3.1. Observe the size of the AR system in comparison to the safety glasses, in Figure 3.1. The AR computing system is compact in size and has the same operating capacity as a Windows 10 PC (Dynabook, 2019).

Figure 3.1. The Toshiba dynaEdge and the DE-100 operating system (Dynabook, 2019).

The study utilized the UBiMAX: xMake software (Ubimax, 2020). The UBiMAX software assisted in the creation of the instructional tasks and the delivery of the tasks for the AD2. The creation of instructional tasks occurred during the AR configuration phase of the study. The software allowed for the flow of the required tasks to be established and understood before the task was started. Checkpoints were established between each step of the assembly tasks to ensure that the end results were correct. The software allowed for the communication of information from the cloud storage to the AR device. The interface of the UBiMAX software is shown below in Figure 3.2. Observe that each block has lines going to and from itself, in Figure 3.2. The lines establish connections between each step in the drag and drop setup.

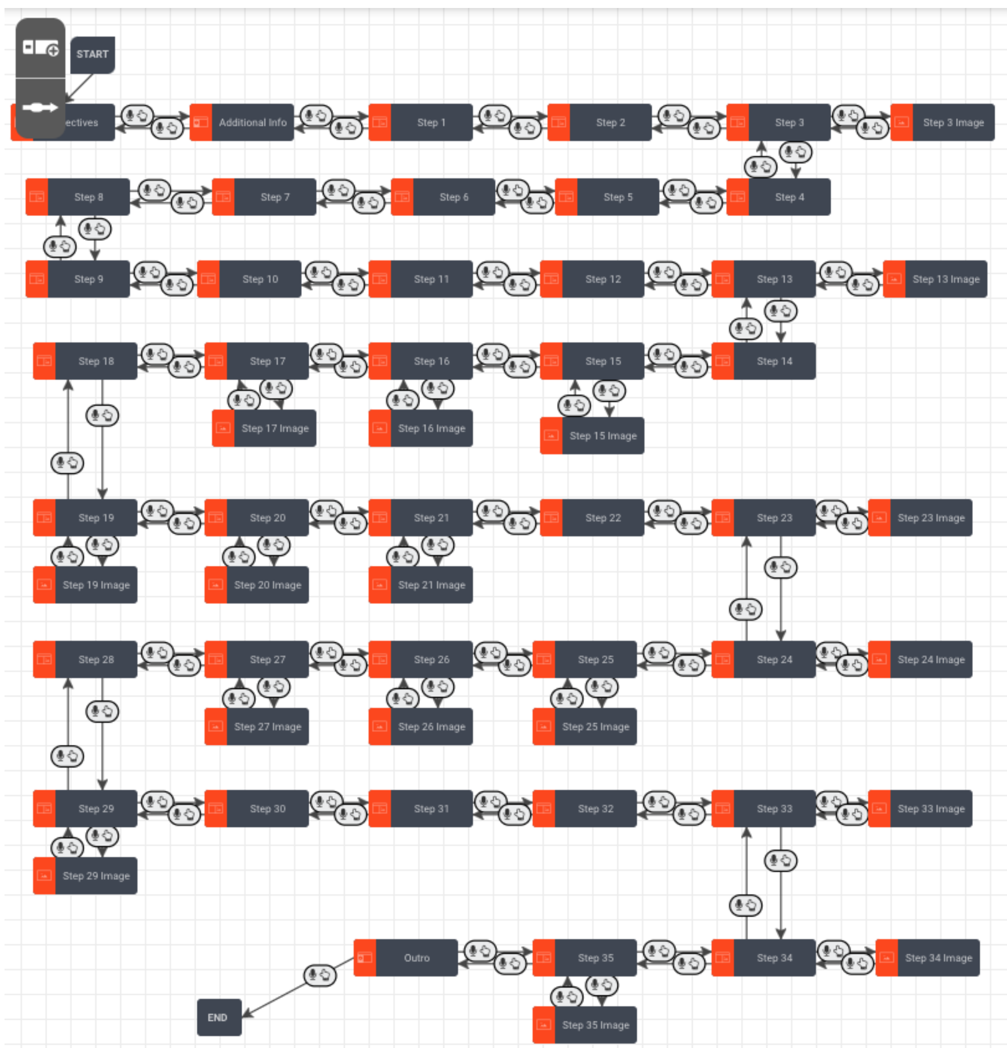

Figure 3.2. The interface of the UBiMAX: xMake software (Ubimax, 2020).

3.4 System Usability Scale

The positive SUS by Sauro and Lewis (2011) was used to determine the perceived usability of the Toshiba dynaEdge AR system. The positive SUS was a modified version of the original SUS that was created by Brooke (1996) and the DEC. The positive SUS utilized a positive tone for all 10 questions, versus the alternating tone that was utilized in the original SUS. The positive SUS was distributed to the operators that used the AR system, during weeks 5 and 8 of the study.

3.4.1 Validation

According to Lewis (2018), concurrent validity was a subcategory of criterion-related validity, which was the correlation between the measure to be used and another measure. Criterion validity specifically being when the measures were taken at the same time (Lewis, 2018). Lewis (2018) stated that the acceptable value for concurrent validity was above .30. Lewis, Utesch, and Maher (2013) compared the SUS and the Usability Metric for User Experience (UMUX) and found a concurrent validity of .90. The UMUX is another means of measuring the perceived usability of a system, similar to the SUS (Lewis et al., 2013). The SUS displayed proof of validity, in regards to other available usability scales.

3.4.2 Utilization

Sauro and Lewis (2011) recommended using the positive SUS if a researcher was not already invested in the original SUS. The study modified the positive SUS by Sauro and Lewis (2011), which is displayed in Figure 3.3. The wording in Figure 3.3 was changed to reflect the use of the Toshiba dynaEdge AR system.

The Positive System Usability Scale

		Strongly Disagree				Strongly Agree
1	I think that I would like to use the Toshiba dynaEdge frequently.	1	2	3	4	5
2	I found the Toshiba dynaEdge to be simple.	1	2	3	4	5
3	I thought the Toshiba dynaEdge was easy to use.	1	2	3	4	5
4	I think that I could use the Toshiba dynaEdge without the support of a technical person.	1	2	3	4	5
5	I found the various function in the Toshiba dynaEdge were well integrated.	1	2	3	4	5
6	I thought there was a lot of consistency in the Toshiba dynaEdge.	1	2	3	4	5
7	I would imagine that most people would learn to use the Toshiba dynaEdge very	1	2	3	4	5
8	I found the Toshiba dynaEdge very intuitive.	1	2	3	4	5
9	I felt very confident using the Toshiba dynaEdge.	1	2	3	4	5
10	I could use the Toshiba dynaEdge without having to learn anything new.	1	2	3	4	5

Figure 3.3. The Positive SUS for the Toshiba dynaEdge that the study used, modified from the Sauro and Lewis (2011) version.

3.4.3 Administration

The Toshiba dynaEdge AR system usability survey was administered for one trial period. The trial period was at the end of the assembly experiment, on the day that the experiment was conducted. The trial period is normally conducted twice, but this study chose to conduct the trial period once, for a key reason. The key reason being that the researcher wanted to eliminate familiarity with the AD2. Distributing the SUS twice would require that the instructional tasks were timed twice. Thus, providing bias for the second round of collected times and skewing the data.

3.5 Analog Discovery 2 Hardware and Software

The study utilized the Analog Discovery 2 (AD2) (Digilent, 2020). The AD2 is a USB oscilloscope, that was operated using the computer software, WaveForms (Digilent, 2015). The AD2 was used to conduct an instructional task time study. The subjects in the time study assembled and configured the AD2, based off of the provided work instructions (See Appendix A). The AD2 configuration provided an instructional process, that has the capabilities to be completed by anyone whom has participated in post-secondary education. The AD2 USB oscilloscope is shown below in Figure 3.4. The AD2 is displayed in Figure 3.4, to provide a visual representation of the device.

Figure 3.4. The Analog Discovery 2: USB Oscilloscope that was used in the study (Digilent, 2020).

The study utilized the Digilent software, WaveForms (Digilent, 2015). The WaveForms software was responsible for controlling the AD2's inputs and outputs. The WaveForms software was used for 80% of the instructional tasks. The main interactions with the software were measuring voltage and generating wave forms with the oscilloscope.

3.6 Data Collection

The data of the study was derived from the sources of evidence. The six sources of evidence were referred to in Section 2.5. Only two of the six sources of evidence were applicable to the study. The two sources of evidence are listed below:

1. Interviews
2. Direct Observations

3.6.1 Interview Evidence

The interview evidence for the study provided guided questions for the informants. The survey style interview provided structured questions that produced quantitative data (R. Yin, 2003). The survey was conducted in the form of a SUS, which was detailed in Section 3.4. The SUS provides 10 questions for the user that determined the perceived usability of the Toshiba dynaEdge AR system. The questions used a positive tone and provided a usability score that ranges from zero to one hundred.

3.6.2 Direct Observation Evidence

The direct observation evidence for the study provided first hand information from the instructional task experiment. The observations of a new technology (i.e. The Toshiba dynaEdge) provided insights to the use and problems that were not made apparent during the survey (R. Yin, 2003). The problems provided insight on what is to be done moving forward, which ensures an efficient and easy to use system.

3.6.3 Respondents

The respondents of the study consisted of Purdue University Undergraduate Students. The study utilized 20 students from the School of Engineering Technology. The students were used in order to provide credibility to the study by using sound minded individuals.

3.6.4 Anonymity

The study did not use any identifying information from the respondents of the study. The identifying information includes, but was not limited to names, student identification numbers, phone numbers, etc.

3.6.5 Instructional Tasks

The instructional task experiment was generated to determine the difference between AR instruction's and paper instruction's. The AR instruction's were generated and distributed by using the aforementioned information in Section 3.3. The paper instruction's were printed single sided on 8.5" x 11" copy paper. A copy of the paper instruction's is listed in Appendix A.

The instructional task experiment included 20 subjects. The 20 subjects were randomly split into two groups, experimental and control. The experimental group consisted of the subjects that used the AR instruction's. The control group consisted of the subjects that used the paper instruction's. The information in both sets of instructions were identical, the only difference being the distribution of the instructions.

The instructional tasks for each subject was timed using a stopwatch. The time started once the oscilloscope kit was touched. The time ended once the subject raised their hand and said "time." The task was completed without the subject having any outside interference or assistance. Once the subject started, the task was completed with only the provided information. The experiment was approved by Purdue University's Institutional Review Board (IRB 2020-377). A copy of the approval can be found in Appendix B.

3.7 Summary

Chapter Three provided the research methodology for the study. The methodology contained the research type, research design, AR hardware and software, the SUS, instructional task hardware and software, and data collection. The research type specified the approach of an exploratory case study. The research design specified how the study was laid out and the conditions from R. Yin (2003) were applied to the study. The AR hardware and software section specified the use of the hardware (Toshiba dynaEdge) and the use of the software (UBiMAX: xMake). The SUS section established the use of the positive SUS (Sauro & Lewis, 2011) and the overall construction and validity of the SUS. The Analog Discovery 2 (AD2) section specified the use of instructional task hardware (AD2) and the use of the software (WaveForms). The data collection specified the forms of evidence that were be used to gather data and make inferences.

CHAPTER 4. RESULTS

The purpose of Chapter Four was to discuss the results of the study's data collection. The results consisted of findings for the instructional tasks and the system usability scale (SUS). Please note, the results pertain to the updated study, as a result of COVID-19.

4.1 Instructional Task Findings

The instructional tasks analysis was based off of the experiment methodology that was provided in Section 3.6.5. The instructional tasks experiment aimed to determine the difference between augmented reality (AR) instruction's and paper instruction's. Both sets of instructions contained all of the same information, the only difference being how the instructions were delivered to the subject. The experiment consisted of 20 total subjects, which were split evenly into two groups for each instructional tasks.

Table 4.1 displays the times from the each instructional task, the difference between each task, the mean values, and the standard deviations. Observe that the paper instructional task had the smaller mean time, with a larger standard deviation, in Table 4.1. The mean values provide a general understanding as to which instructional task method minimizes the time to complete the given task. Whereas, the standard deviation provides insight into the spread of each data set. The completion time was minimized with the paper instructions, but the data set values were not as precise as the AR instructions. Meaning that the paper instructions did not take as long to complete, but the overall data set consisted of more variation.

Table 4.1. *AR and Paper Instruction Times*

	AR(min)	Paper (min)	Difference (min)
	11.88	7.53	4.35
	9.95	8.98	0.97
	6.17	7.47	-1.3
	12.38	13.63	-1.25
	7.4	6.43	0.97
	8.83	11.68	-2.85
	8.25	8.4	-0.15
	11.52	9.63	1.89
	10.92	12.95	-2.03
	10.17	10.53	-0.36
Mean	9.747	9.723	0.024
SD	2.044	2.431	2.109

Figure 4.1 provides a visual representation of how the times for both instructional tasks varies across the average for all 10 runs. The times in Figure 4.1 are displayed in minutes. Observe how the data points align with the average line, in Figure 4.1. The data points teeter across the average line, with one point from each data set being within .22 minutes (13.2 seconds) of the average.

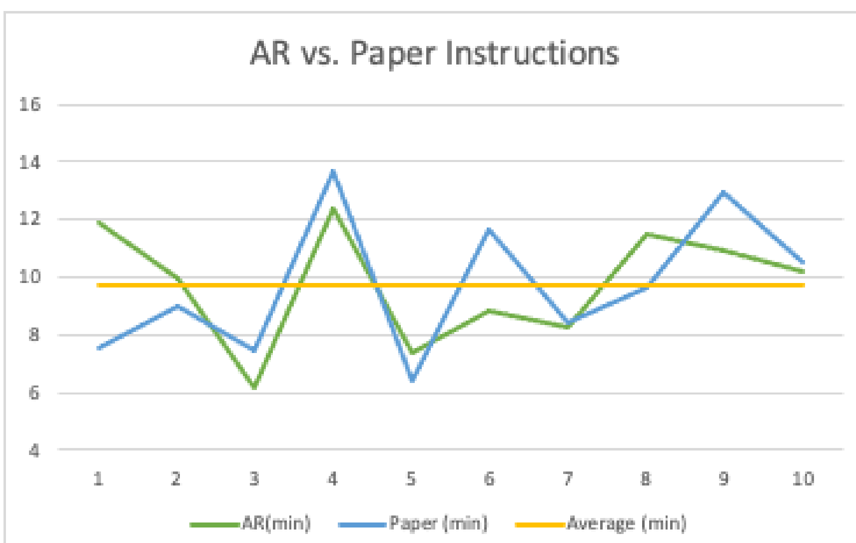

Figure 4.1. A visual representation of the times that were collected from the instructional tasks.

The collected times from the instructional tasks were analyzed using the statistical software, *JMP (Version 15.1.0)* (SAS Institute Inc., 2019). The software, *JMP*, was used to conduct a two-sample t-test, as well as an Cohen's d effect size analysis. The two-sample t-test is recommended when trying to understand if the means of two populations are equal to each other (NIST/SEMATECH, 2013). The t-test provided an understanding of the relationship between the AR times and the paper times. Table 4.2 displays the t-test information that was generated by *JMP*. The p-value that was used from Table 4.2 is labeled as $Prob < t$. The used p-value in Table 4.2, determines if there is statistical significance based off of the 95% confidence interval. A statistically significant p-value for the 95% confidence interval is .05 or less.

Table 4.2. *JMP T-test Table (SAS Institute Inc., 2019).*

t Test

Paper-AR

Assuming unequal variances

Difference	-0.0240	t Ratio	-0.02389
Std Err Dif	1.0045	DF	17.4845
Upper CL Dif	2.0908	Prob > |t|	0.9812
Lower CL Dif	-2.1388	Prob > t	0.5094
Confidence	0.95	Prob < t	0.4906

The study's null hypothesis and alternative hypothesis are shown below:

$$H_0 : \mu_{AR} = \mu_P \tag{4.1}$$

$$H_a : \mu_{AR} - \mu_P < 0 \tag{4.2}$$

Based off of the p-value from the t-test, the null hypothesis has failed to be rejected with 95% confidence. The statistically evidence does not support the hypothesis of the AR mean time being less than the paper mean time.

4.1.1 Cohen's D Effect Size Analysis

The Cohen's d effect size was calculated to determine if there is a correlation in the differences of the instructional tasks (Coe, 2002). According to Coe (2002), Cohen's d effect size is calculated with following equation:

$$EffectSize = \frac{\mu_{Experimental} - \mu_{Control}}{StandardDeviation} \tag{4.3}$$

According to Lakens (2013), effect size is classified as followed:

Small: d=.2,

Medium: d=.5,

Large: d=.8

The statistical software, *JMP*, was used to calculate the study's effect size (SAS Institute Inc., 2019). The study's Cohen's d effect size was reported as $d = .01069$. Based off of the information provided by Lakens (2013), the effect size for the study fits into the small category. The study's effect size is classified as a small effect size, due to the *d* being less than .2. Meaning that the difference in the values of the AR and paper instruction's is insignificant, thus not having a correlation.

4.1.2 Instructional Task Dry Run

Before the instructional task study was conducted, a dry run had occurred with the paper instruction's. The dry run was conducted with a Purdue University Professor. The purpose of the dry run was to identify problems within the instructions and to gather an estimate for the completion time. The completion time for the dry run was 17.93 minutes. During the dry run, input errors occurred, thus increasing the overall completion time. The errors in the instructions were related to a missing step, which lead to incorrect screen setup options for the WaveForms Software (Digilent, 2015).

4.2 System Usability Scale Findings

The positive system usability scale (SUS) analysis was based off of the provided information in Section 2.6. The positive SUS was used to determine the perceived usability of the Toshiba dynaEdge AR100 viewing system (Dynabook, 2019). Due to a change in the study, the positive SUS was only distributed to the participants once, instead of twice. The calculated positive SUS scores are shown in Table 4.3. Observe the mean score of the data set, in Table 4.3. The mean score is used to determine the perceived usability of the AR system.

Table 4.3. *The Positive SUS scores for the Toshiba dynaEdge.*

	Positive SUS Scores
	77.5
	52.5
	90
	62.5
	70
	85
	100
	62.5
	67.5
	67.5
Mean	73.50
SD	15.21

According to Bangor, Kortum, and Miller (2009), a passing score for the SUS is 70. A passing SUS score means that the specified system is useful for the task at hand (Bangor et al., 2009). The specified system for this study, being the Toshiba dynaEdge AR100 (Dynabook, 2019). Thus concluding, that the Toshiba dynaEdge was perceived to be useful because of the 73.50 positive SUS score.

4.3 Summary

Chapter Four provided the results of the findings from the instructional tasks analysis and the SUS analysis. The instructional tasks data was analyzed through a t-test and effect size analysis, which was conducted with the statistical software, *JMP* (SAS Institute Inc., 2019). The results of the t-test concluded that there was not statistical significance in regards to the alternative hypothesis. Meaning that the AR instruction's were not concluded to produce quicker results than the paper instruction's. The results of the Cohen's d effect size analysis concluded that the effect size for the instructional tasks was small. Meaning that there was not a correlation between the differences of the AR and paper instructions. The SUS data was analyzed and the average score was calculated to be 73.50. The SUS score of 73.50 provided evidence that the Toshiba dynaEdge was perceived to be useful, among the AR subjects.

CHAPTER 5. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Chapter Five tied together the information from Chapters One through Four. Chapter Five summarizes and concludes the aforementioned information, as well as provides recommendations for the study, moving forward.

5.1 Summary

The study was originally formed to address the problem of 60% of lean production implementations resulting in failure (Pearce & Pons, 2019). The failed lean systems are attributed to a poor understanding of lean principles and a lack of commitment from employees and leadership (Almanei et al., 2018). The study chose to improve the percentage of failed lean systems with technology, specifically, augmented reality (AR). Augmented Reality has the ability to provide hands free information to the user via three-dimensional object overlap, word documents, pictures, and videos (Kipper & Rampolla, 2012). The use of AR would provide a better understanding of lean principles, by providing lean related information, in real time situations. Using AR would also constantly reiterate lean information to the user, thus ensuring that the user is staying committed to the practices.

The AR system that was chosen for this study is the Toshiba dynaEdge AR100 (Dynabook, 2019). The dynaEdge is a head mounted display (HMD), that is powered by the Toshiba dynaEdge DE-100 mini computing system (Dynabook, 2019). The AR system provided hands free instructions that also contained pictures and videos. The instructions for the dynaEdge were created using the UBiMAX: xMake software (Ubimax, 2020). The UBiMAX software consisted of a drag and drop interface, that allowed for individual steps to be set up and then connected.

The study was originally going to be based around the Fiat Chrysler Automobile (FCA) transmission gear manufacturing process. Due to the COVID-19 pandemic (Wang et al., 2020), the study's focus was changed to measuring the difference between different types of instructions. The study focused on two types of instructions, AR instruction's and paper instruction's. Both instructions were identical in content, the only difference was how the instructions were delivered.

The study utilized the Analog Discovery 2 (AD2) USB oscilloscope for the instructional tasks (Digilent, 2020). Along with the *WaveForms* software, which powers and configures the AD2 (Digilent, 2015). The AD2 was in the instructional tasks as an assembly kit. The AD2 assembly was timed for both the AR instruction's and the paper instruction's.

The timed portion of the study utilized 20 subjects that were split evenly into two groups, one for each instruction type. After all of the times were collected, a t-test analysis and a Cohen's d effect size analysis were conducted. Both the t-test and the Cohen's d effect size analysis were conducted using the statistical software, *JMP* (SAS Institute Inc., 2019).

During the study, the positive system usability scale (SUS), from Section 3.4.2 was distributed after every AR instructional run. The purpose of the SUS was to determine the perceived usability of the AR system. The perceived usability provided an understanding as to how useful the Toshiba dynaEdge was perceived to be, amongst the subjects. The perceived usability was important in establishing a system that would actually be used. If the AR system conveys information appropriately, but would not get used, then incorporating the system into a process would be useless.

5.2 Recommendations

During the study, observations were made that may be useful to future research. The observation categories pertain to the AR system, the USB oscilloscope, and the study's sample size. The recommendations are not cure-all solutions to problems that were encountered, but they may help to improve future studies.

5.2.1 Augmented Reality System

The first recommendation pertains to the AR computing system. The AR system came with the DE-100, a computing unit that powers the dynaEdge with a Windows 10 processing system (Dynabook, 2019). The DE-100 was bulky and a hindrance at times, mainly due to the size. The computing system measured out to be 6.500”x3.375”x.813”, which is the size of some modern phones. The system is just an extra piece of equipment that must be carried around for the experiment. Having access to a Windows 10 capable system was convenient, but not a necessity for the study. There are other AR systems that do not require the use of an external PC, that would suffice for the study. Moving forward, it is recommended to use an AR system, that does not require an external PC unit.

The second recommendation pertains to the utilization of the AR system. The AR system has the capabilities to be used via voice commands or mouse commands. The voice commands allows the device to be used in a hands free manner, while the mouse commands require hands on interactions. During the experiment, it is recommended that the subjects only utilize the voice commands feature. The voice command feature gives the experiment a 100% hands free instructional task experience. The use of the mouse commands create an experience that is similar to using paper instructions, since hands on interaction is needed.

5.2.2 USB Oscilloscope Kit

The third recommendation pertains to Analog Discovery 2 (AD2) USB oscilloscope kit (Digilent, 2020). The AD2 was configured and powered by the software, *WaveForms* (Digilent, 2015). When using the *WaveForms* software, value entry occurs through one of two methods. The methods consist of typing in the values or clicking a drop down menu and selecting the values. Either method is suitable for the experiment, but completion times may vary based off of the selected method. During the experiment, it is recommended that one of the two methods are specified for the subjects to use. Specifying one of the two methods alludes to a increase in reliability for all time measurements.

5.2.3 Sample Size

The fourth recommendation pertains to the sample size of the study. The study's sample size was limited to 20 subjects, due to the ongoing COVID-19 pandemic. The sample size must be 30 or greater, in order to make the assumption that the study's data is normally distributed. During the future experiments, it is recommended that a minimum of 30 subjects are gathered for the study.

5.3 Conclusion

Throughout this document, the focus has been on the impact of incorporating augmented reality (AR) into an existing system. Whether the system is lean manufacturing based or requires daily completion of instructional tasks. Augmented reality incorporation provides the user with hands free information, which helps with task completion and information retention. The study performed a proof of concept for the overall usefulness of AR, in comparison to traditional methods. The study was driven by the following research question:

- How did instructional tasks times compare between AR instruction's and paper instruction's?

The posed research question resulted in an experiment being set up, that utilized the Analog Discovery 2 (AD2), as an assembly kit (Digilent, 2020). The AD2 was to be configured based off of AR instruction's and paper instruction's. Where the AR instruction subjects were the experimental group and the paper instruction subjects were the control group. Both groups were provided with the same information and the same experimental lay out, in order to obtain precise time measurements.

The experiment resulted in the paper instruction's having a shorter completion time than the AR instruction's. The result was the opposite of the study's hypothesis, which was that the AR instruction's would provide a faster completion time. After the completion time of the AR instruction's were deemed to be slower than the paper instruction's, a t-test was conducted.

The two-sample t-test was conducted to determine if there was statistical significance between the means of both instructions. The two-sample t-test concluded that there was not statistical evidence to support the claims of the aforementioned hypothesis. The results of the t-test lead to a conduction of a Cohen's d effect size analysis. The effect size analysis was conducted to determine if there is a significant difference between the means. The Cohen's d effect size analysis resulted in the means not containing a significant difference.

The results for the time comparisons did not report as hypothesized, which resulted in the AR system's usability being questioned. The AR's perceived usability was determined through the use of a system usability scale (SUS). The SUS's purpose was to provide quantitative evidence, that the Toshiba dynaEdge was useful (Dynabook, 2019). The SUS resulted in a passing score, which is 70 or higher. Meaning that the AR system was indeed useful and the results experiment are not directly correlated to the AR system itself.

Even though the results of the study were opposite of what was expected, the study still holds value. The study provides an experiment that was not successful, but provides future researchers with a starting point. To future researchers, use the information from this study and the information in Section 5.2 to advance your own study's. The question moving forward is ”How can augmented reality be used to optimize a system's performance?”

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APPENDIX A. DIGILENT ANALOG DISCOVERY 2 INSTRUCTIONS

Digilent Analog Discovery 2 Instructions

* This study has been vetted by the Purdue University 2020 Institutional Review Board.

Objectives

- Provide an understanding of how to configure the device to measure the change in voltage over time.
- Determine the difference between paper instructions and digital hands-free instructions.
- Determine the perceived usability of the AR system.

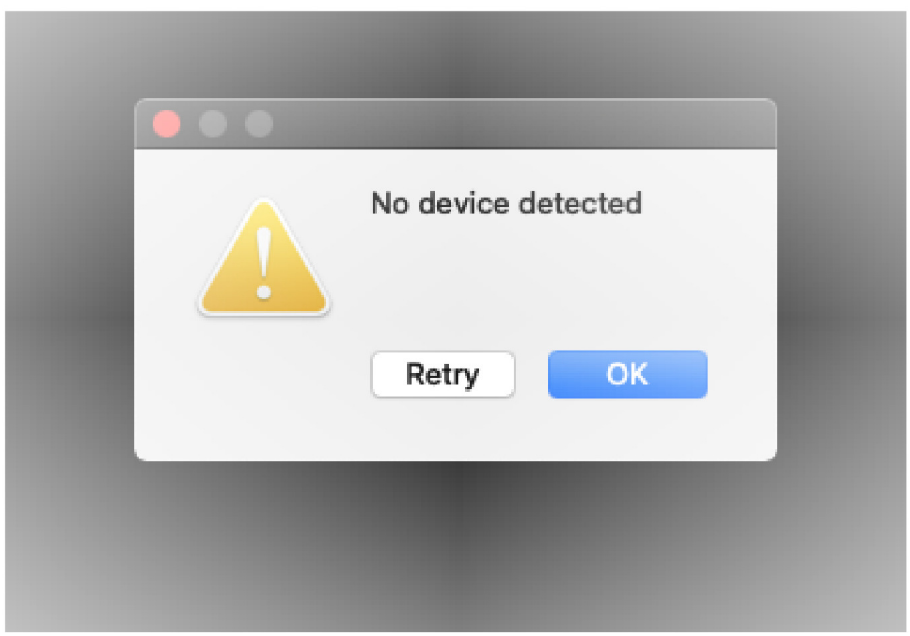
Additional Information

- The tasks will be completed without outside interference or assistance.
- Once the time starts, the participant will complete the tasks with only the provided information.
- The time will start once the oscilloscope kit has been touched.
- The time will end once the participant raises their hand and says “time”.

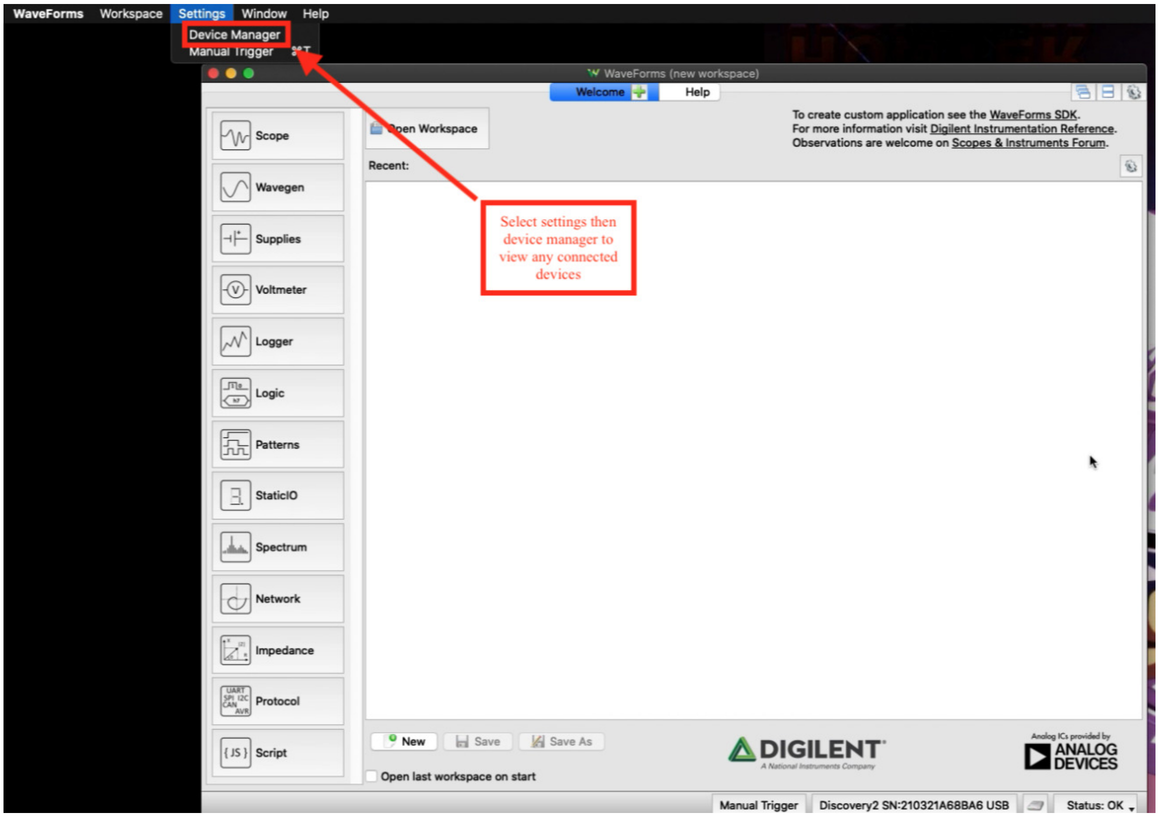
Configuring the Analog Discovery 2 (AD2) Oscilloscope

1. Connect the AD2 to the computer using the provided micro USB cable.

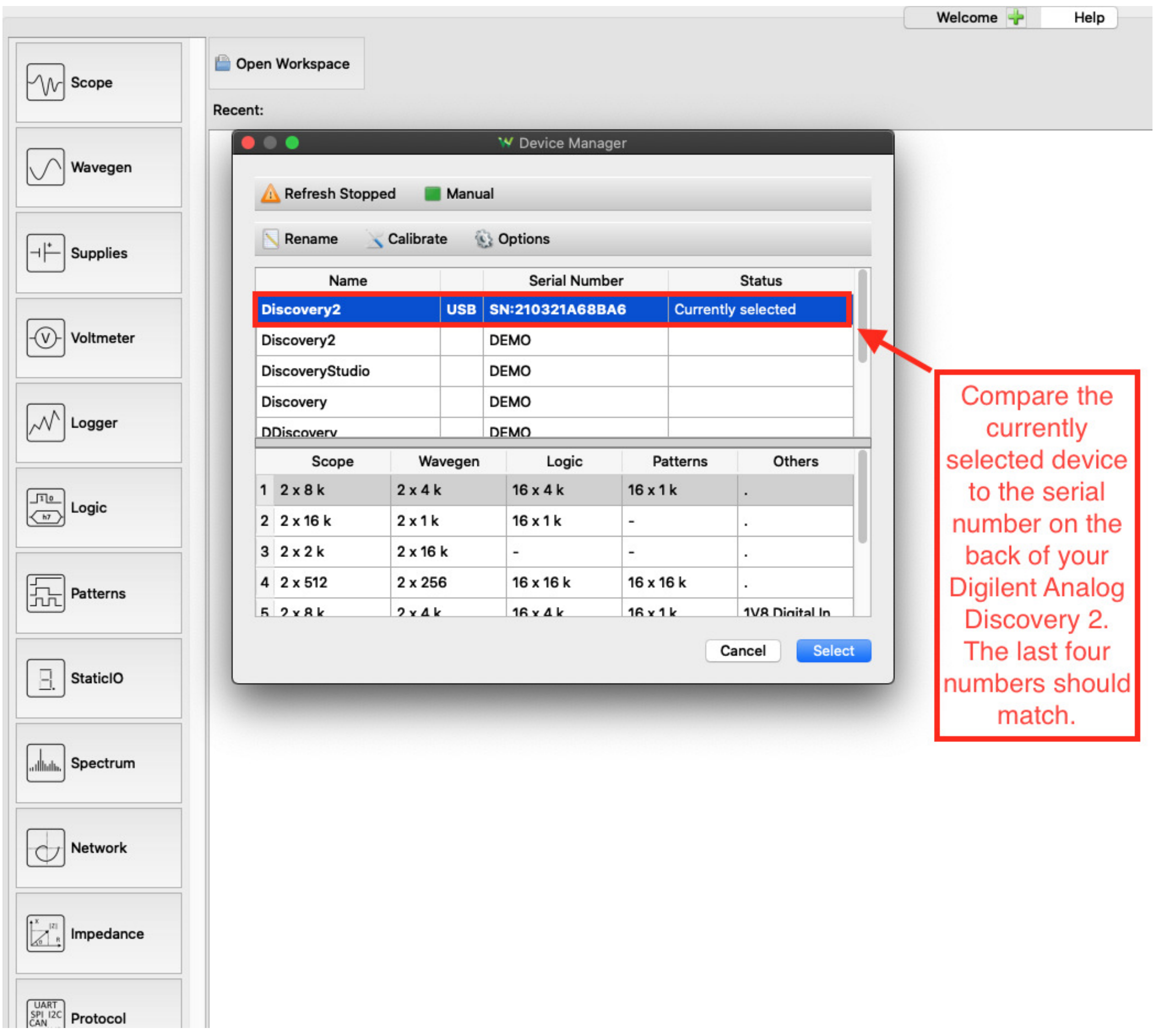
2. Click the “retry” button to connect the device to the Waveform software.



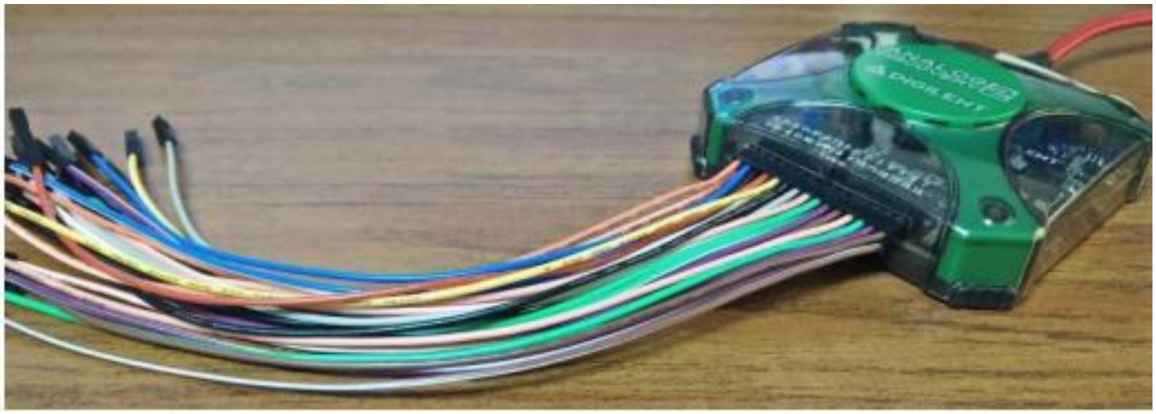
3. If the device manager window does not automatically open, then click settings => Device Manager.



4. Compare the serial number of the top listed device in the Device Manager window to the serial number on the bottom of the AD2. Press select after verifying that the serial numbers match.
    a. If the numbers do not match, then restart software.

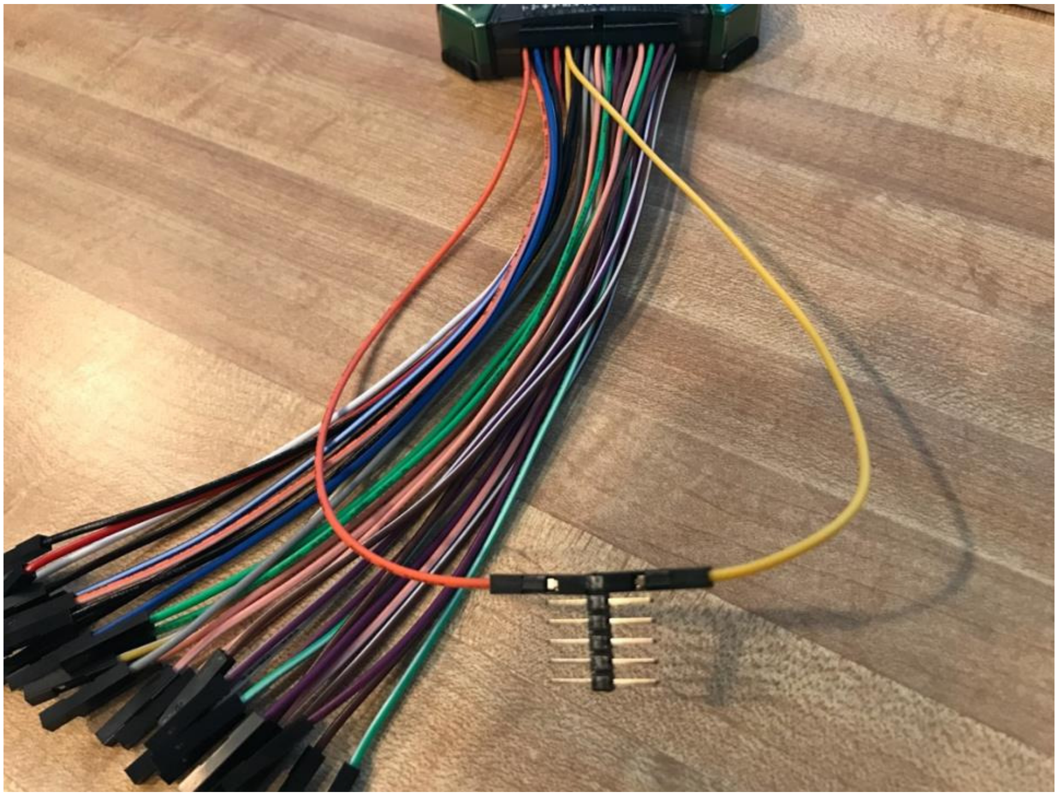


5. Connect the 2.54 mm ribbon cable to the AD2.

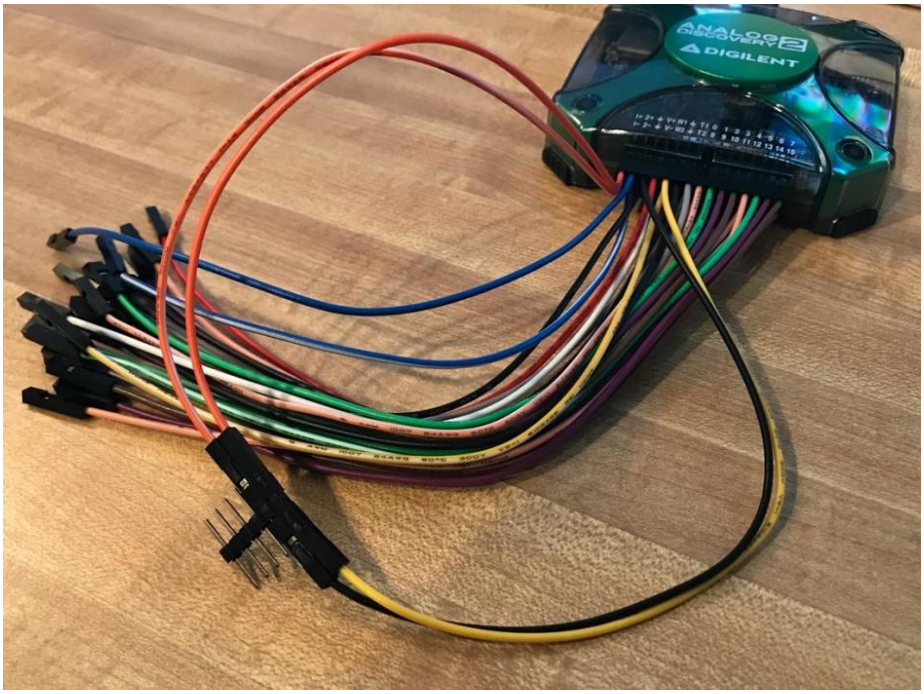


6. Note that there are wire labels above the ribbon cable connection port.

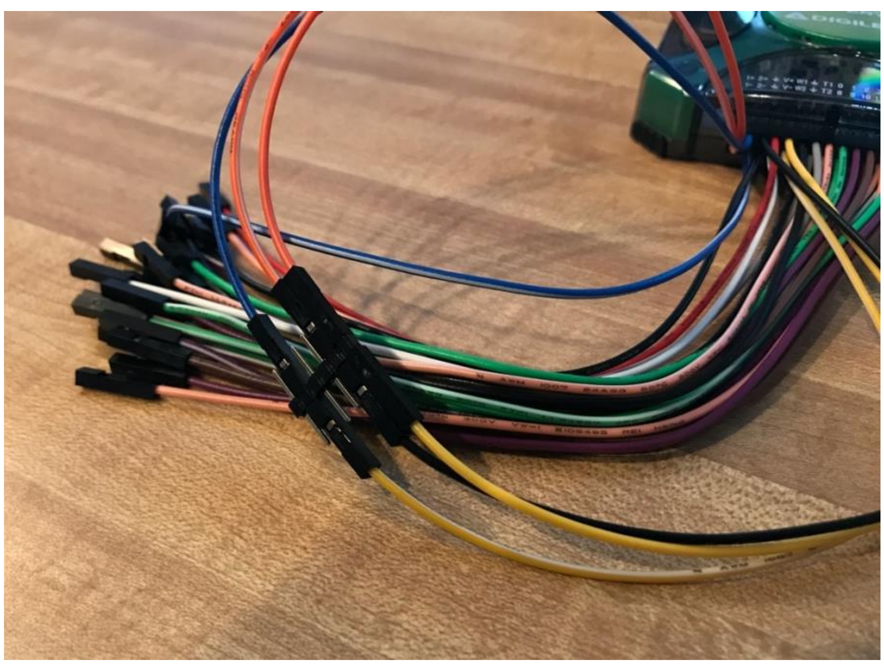
7. Connect the upper yellow (W1) and orange (1+) wires to the pin connector.



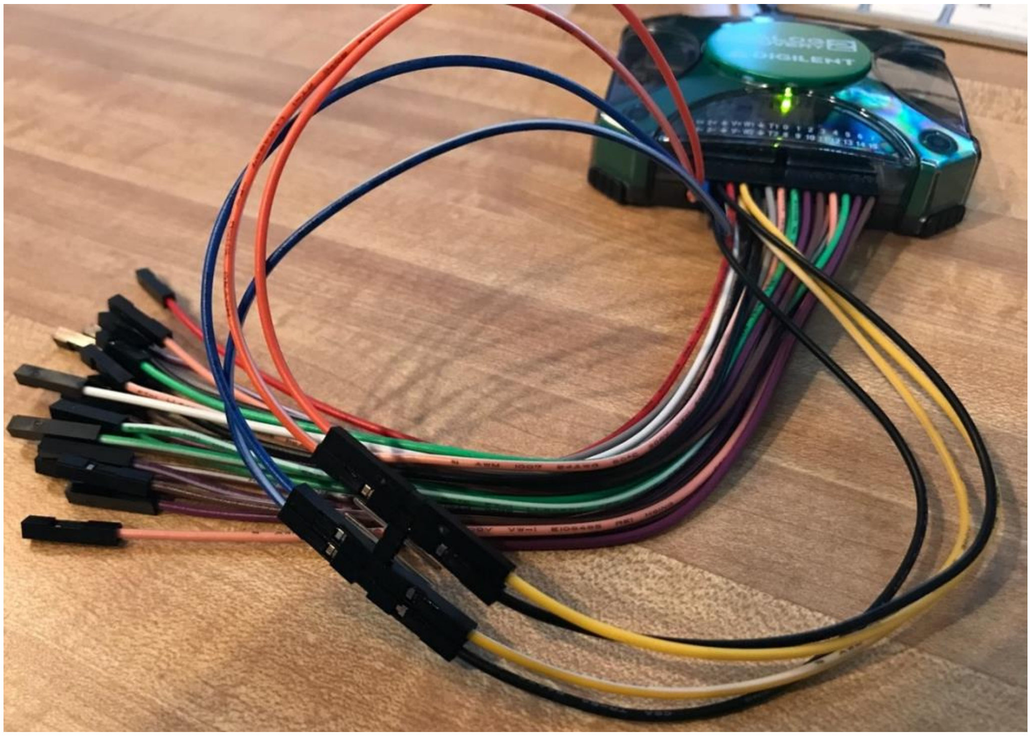
8. Connect any black wire (↓) and the orange wire with a white stripe (1-) to the pin connector.



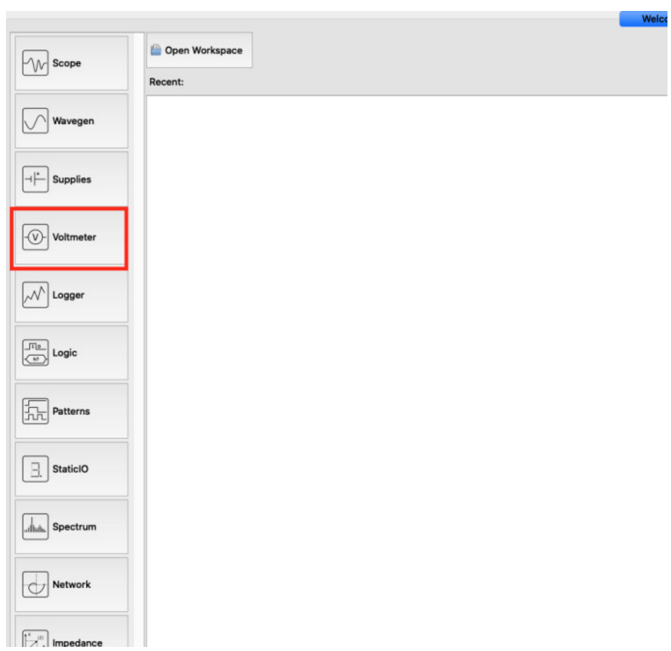
9. Connect the upper blue (2+) wire and the yellow wire with a white stripe (W2) to the pin connector.



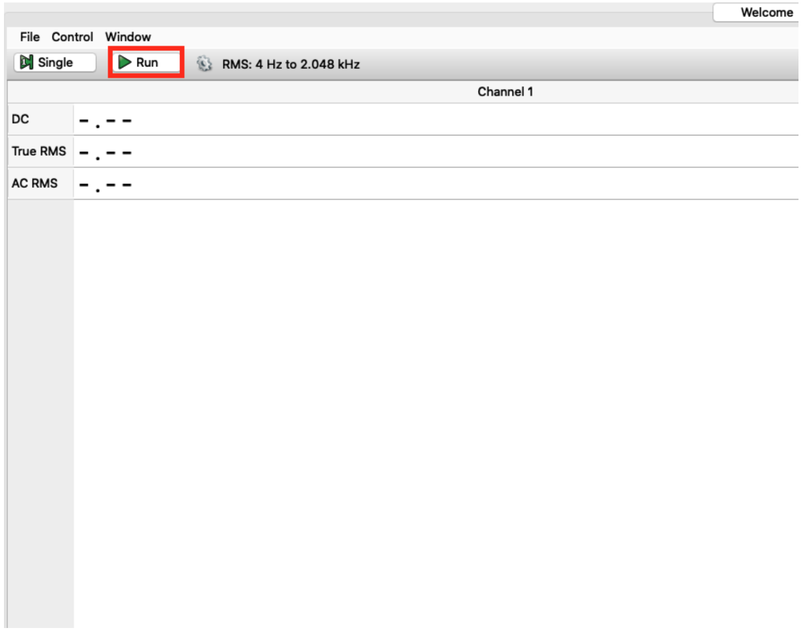
10. Connect any black wire (↓) and the blue wire with a white stripe (2-) to the pin connector.



11. Open the Voltmeter Instrument panel

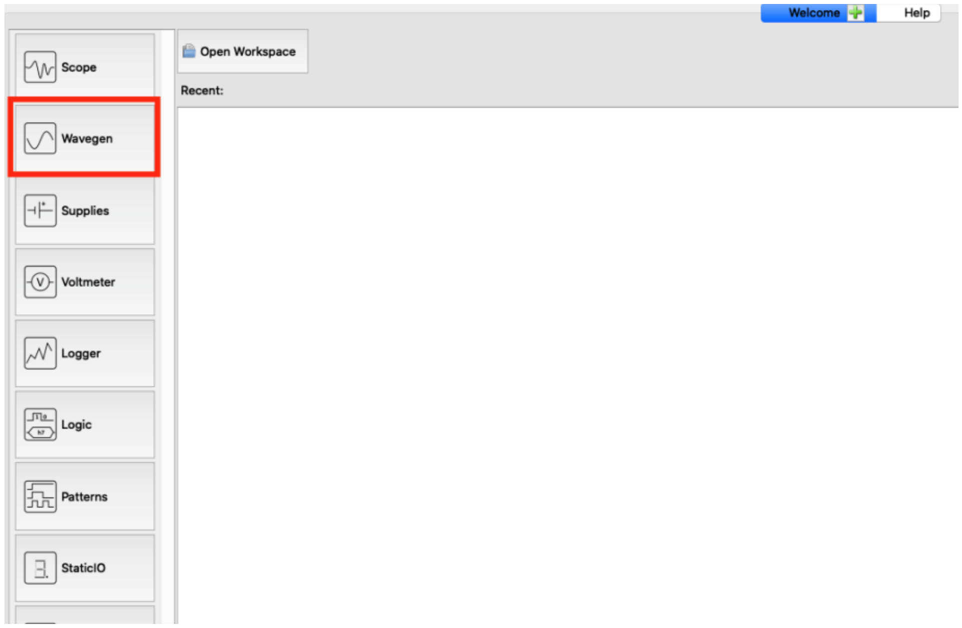


12. Click the green run button

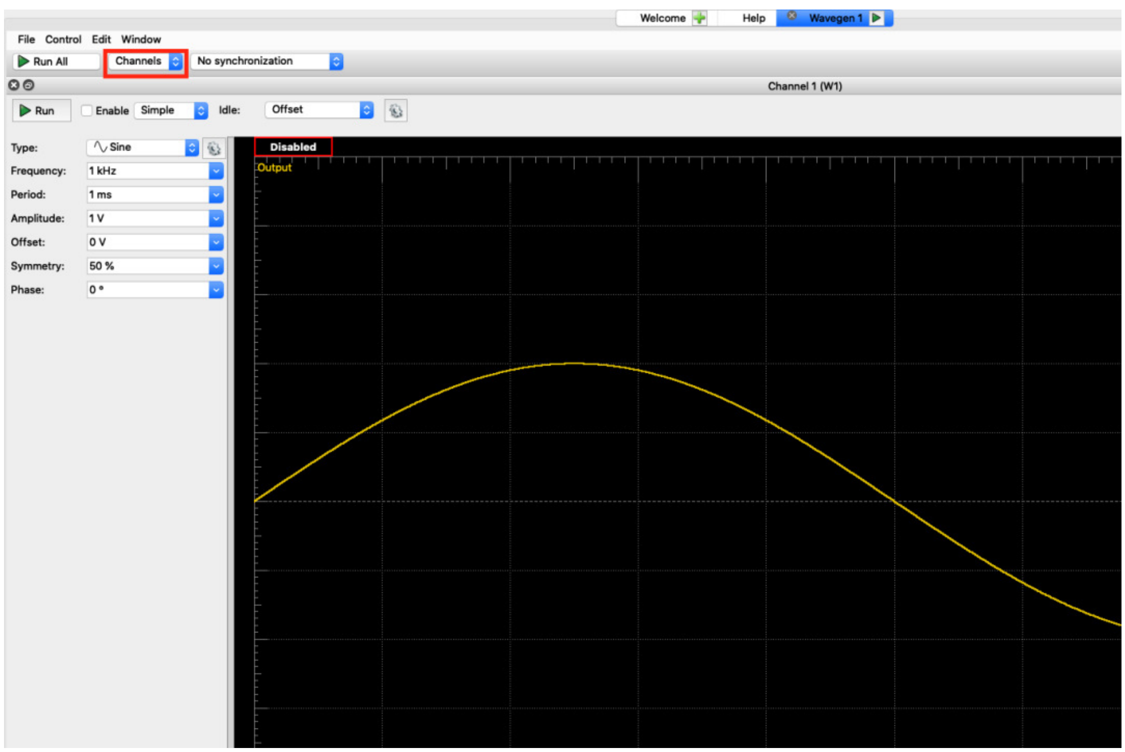


13. Click the “welcome” button at the top of the screen to return to the opening screen.

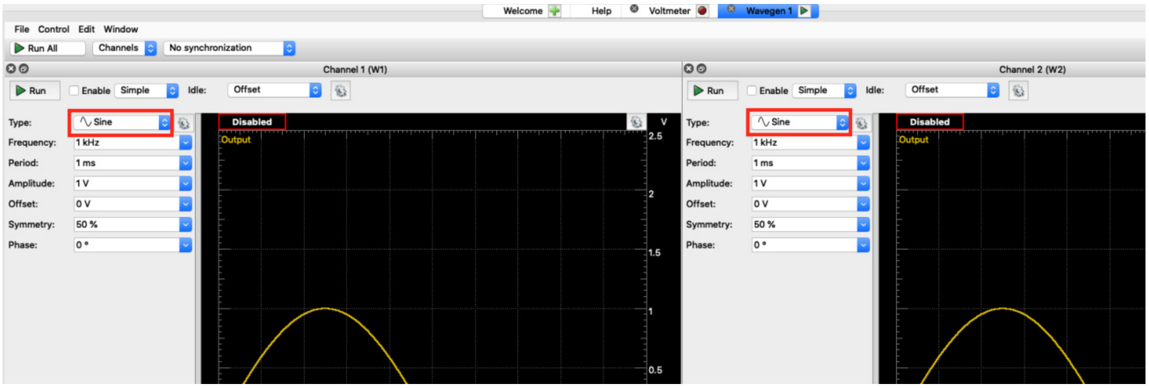
14. Open the Wavegen Instrument panel



15. Click on the "Channel" button and select Channel 2.



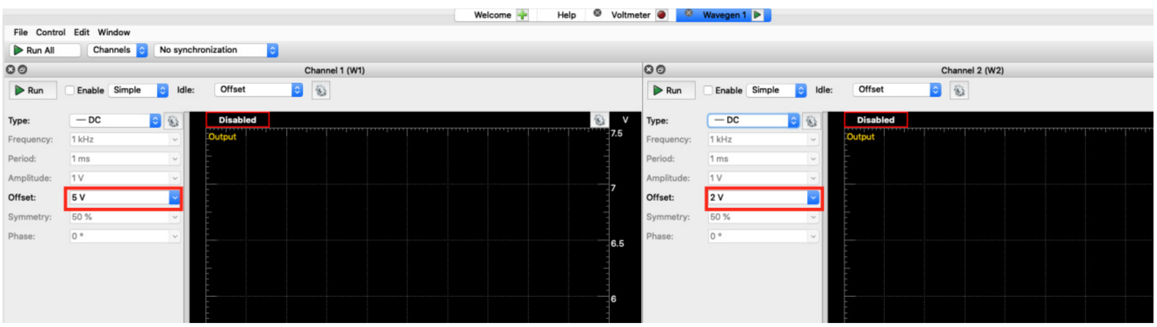
16. Change both channel types to DC



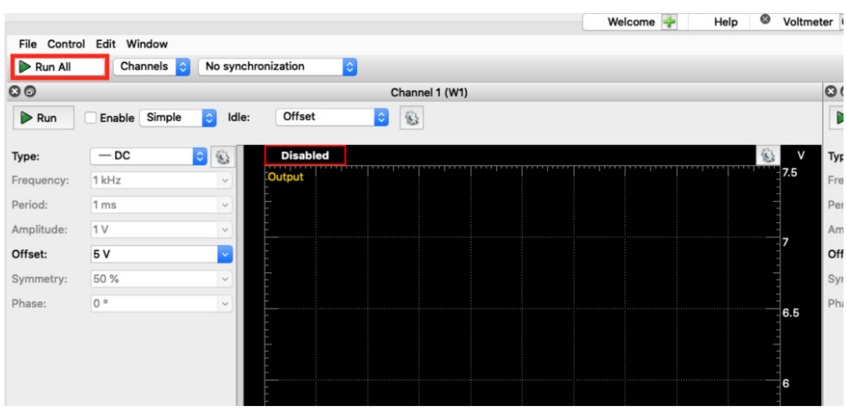
17. Change the offset voltage values to be as followed:

a. Channel 1 = 5V

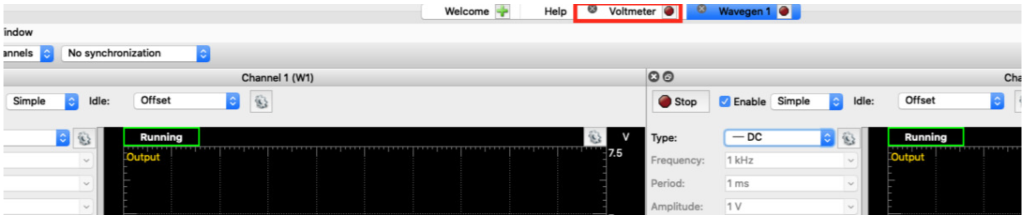
b. Channel 2 = 2V



18. Click the green "run all" button at the top left of the screen.



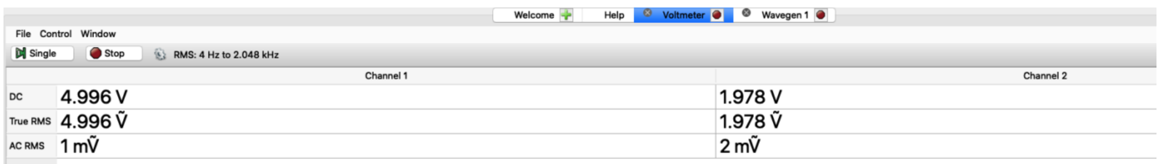
19. Click the “voltmeter” button at the top of the screen.



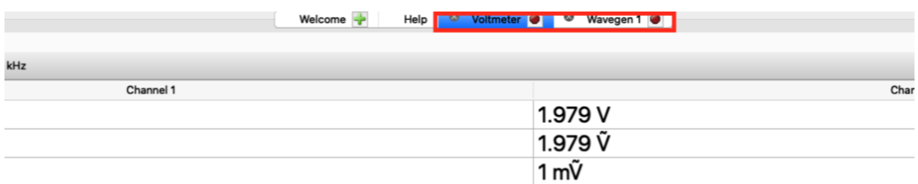
20. Verify that the values for channel 1 and channel 2 match the entered values:

a. Channel 1 = 5V ±.1V

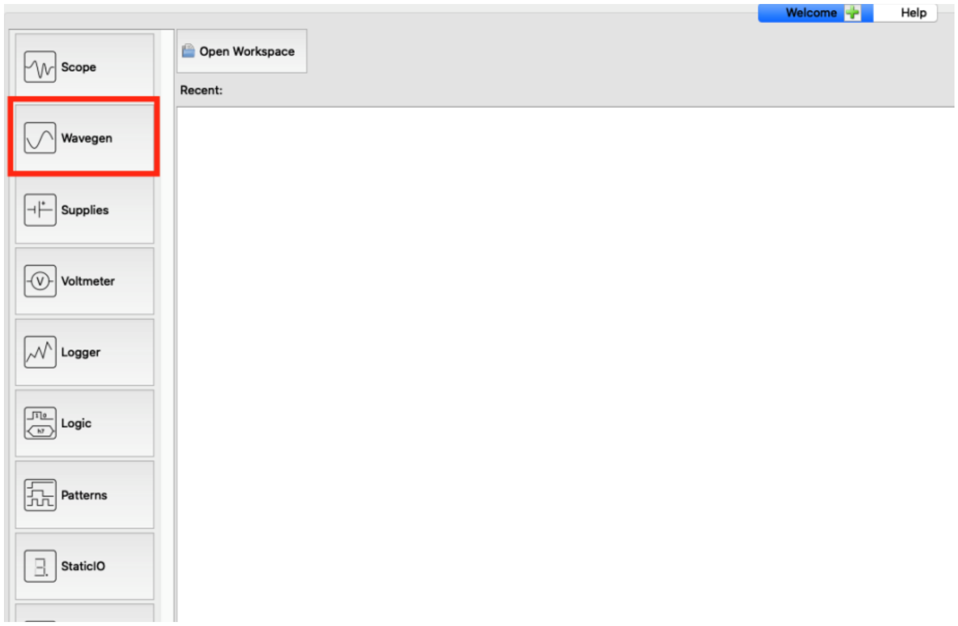
b. Channel 2 = 2V ± .1V



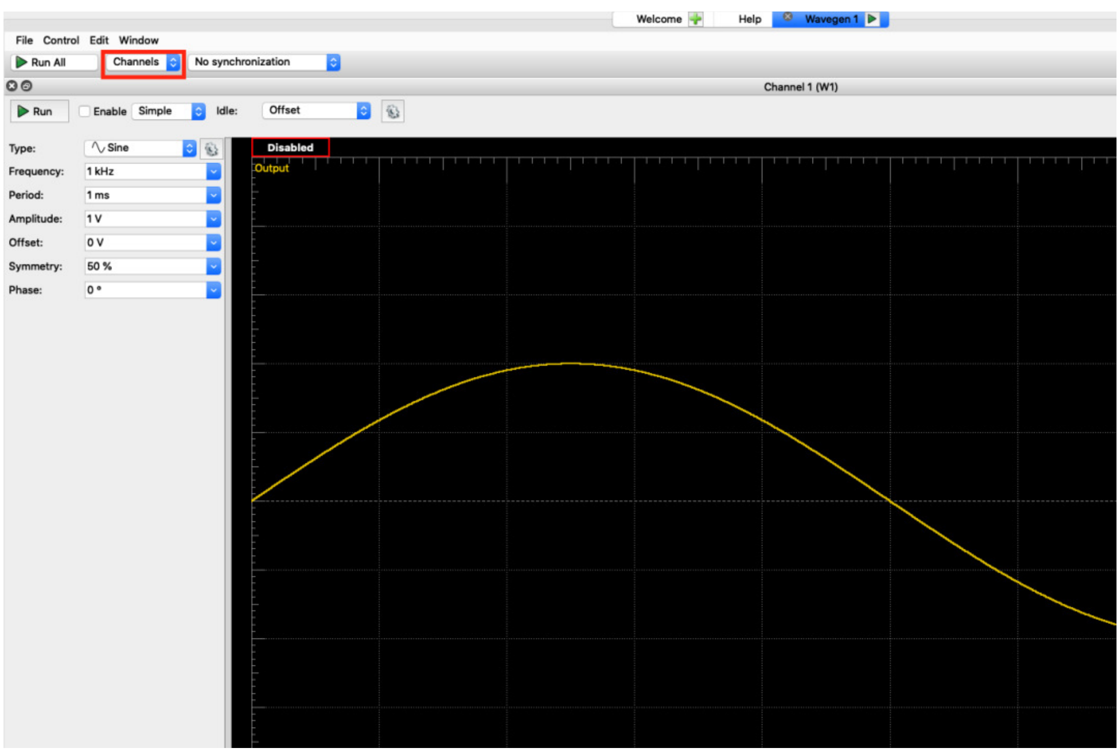
21. After verifying the values, close out the voltmeter and wavegen windows by clicking the “x” beside their names.



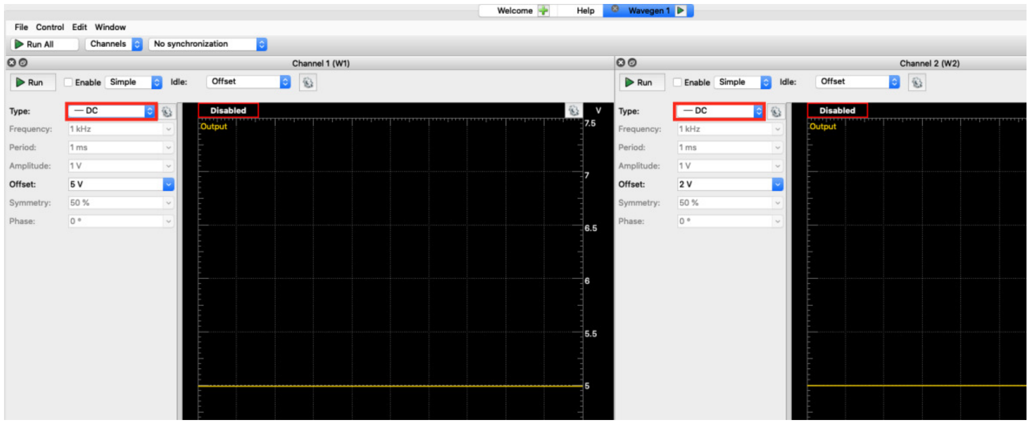
22. Open the Wavegen Instrument panel



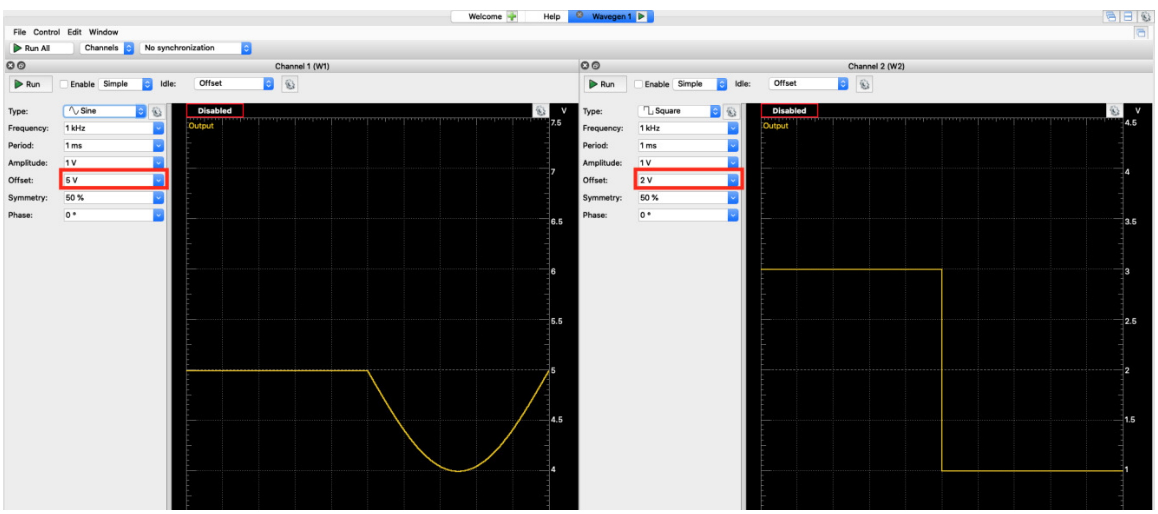
23. If both channel windows do not appear, then click on the Channel button and select Channel 2.



24. After the Channel 2 window appears, click on the wave type and select “square”. Make sure the channel 1 type is set to “sine”

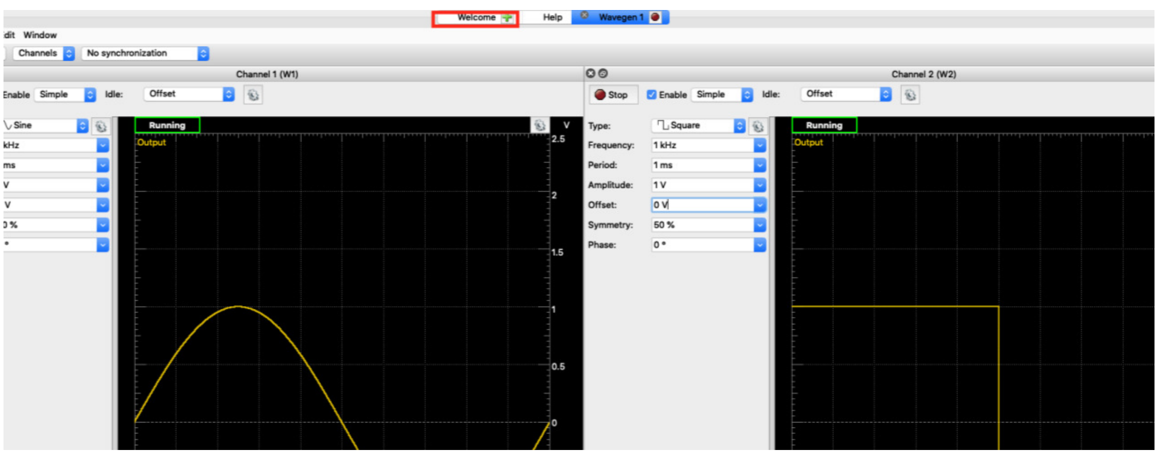


25. Change the offset value of both channels to be “0 V”.

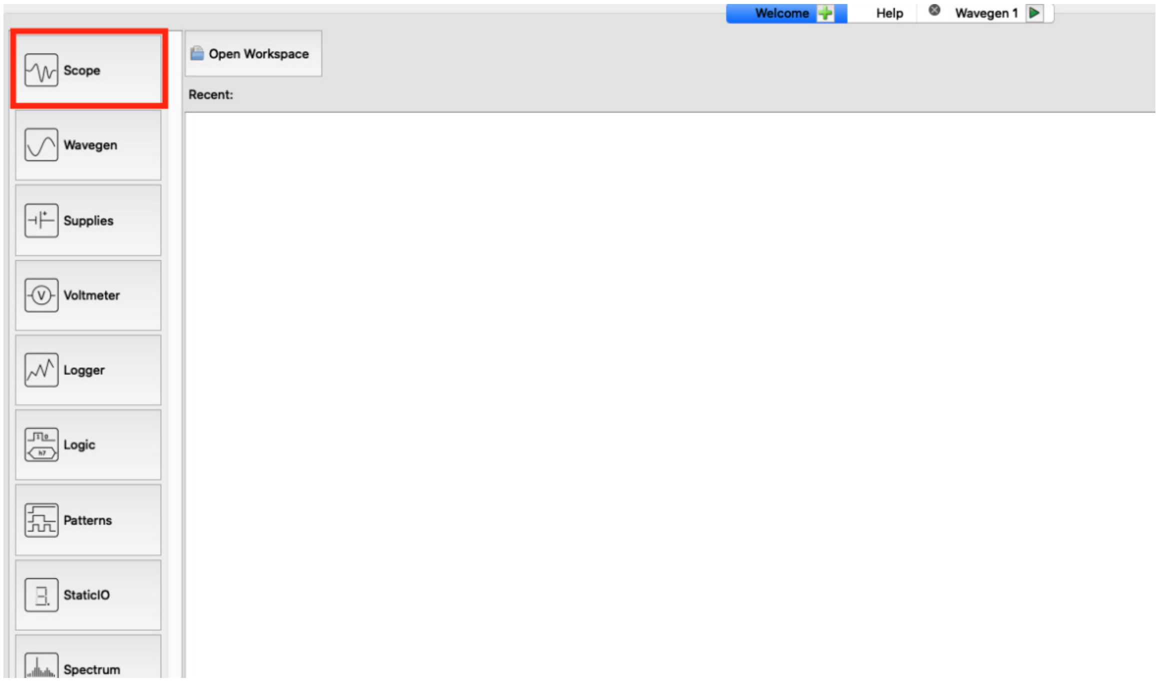


26. Click the green run all button at the top left of the window, to run the wave.

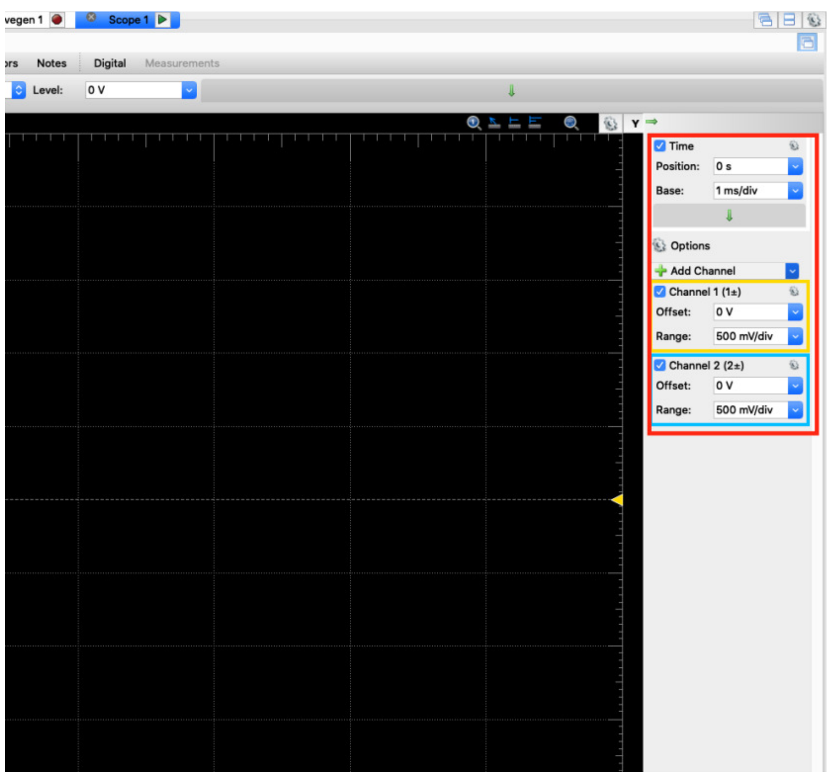
27. Click the “welcome” button at the top to return to the main screen.



28. Open the Scope Instrument panel



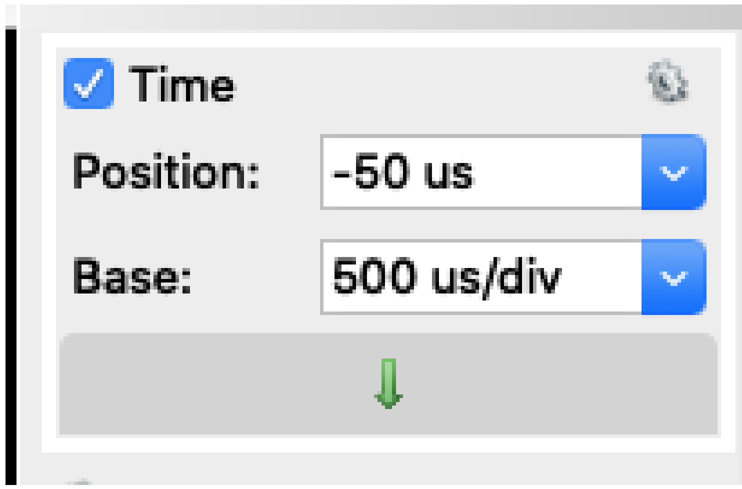
29. Locate the settings for Time, Channel 1 and Channel 2, on the right side of the screen.



30. Adjust the time values to be as followed:

    a. Position = -50us

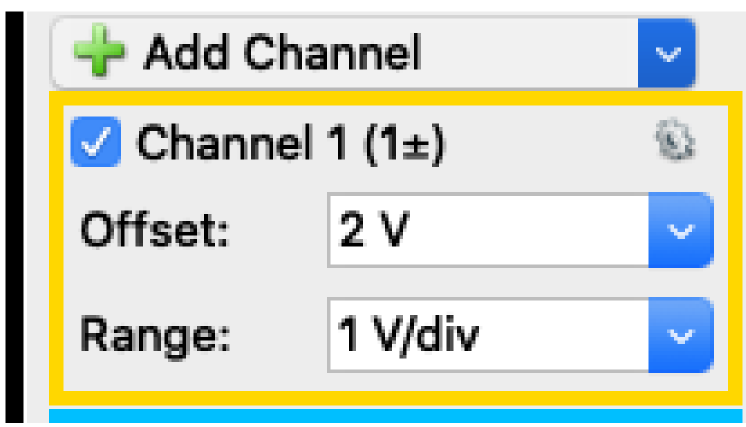
    b. Base = 500 us/div



31. Adjust the Channel 1 values to be as followed:

    a. Offset = 2V

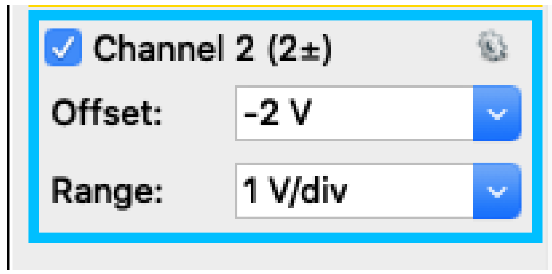
    b. Range = 1 V/div



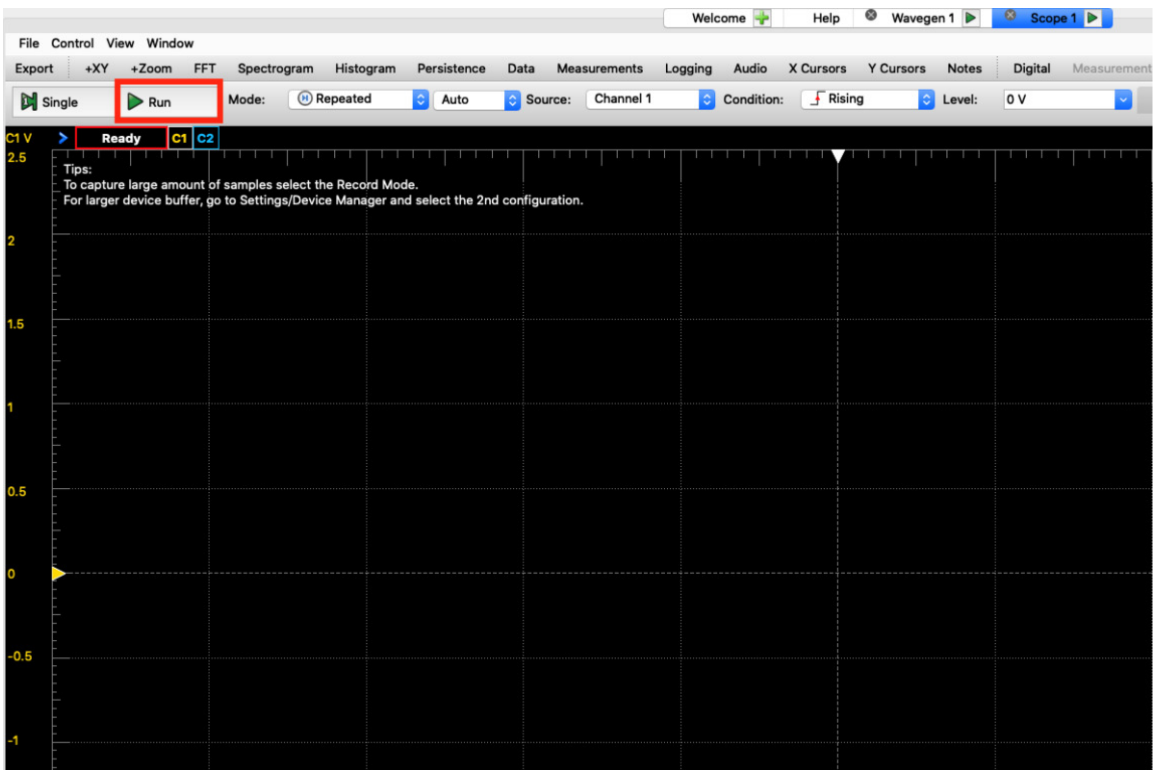
32. Adjust the Channel 2 values to be as followed:

    a. Offset = -2V

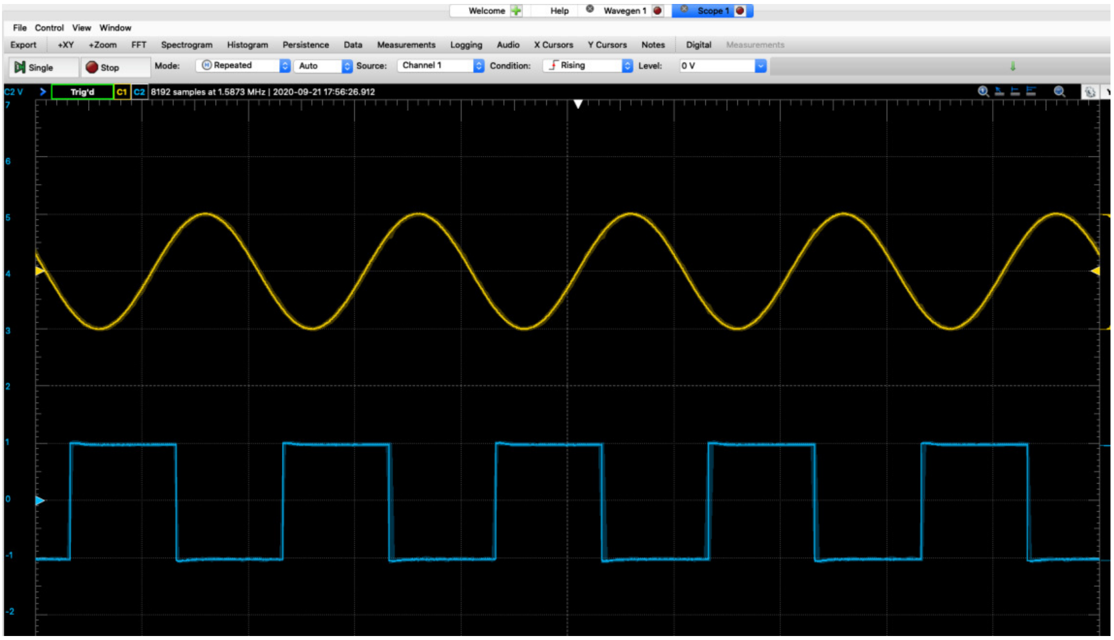
    b. Range = 1 V/div



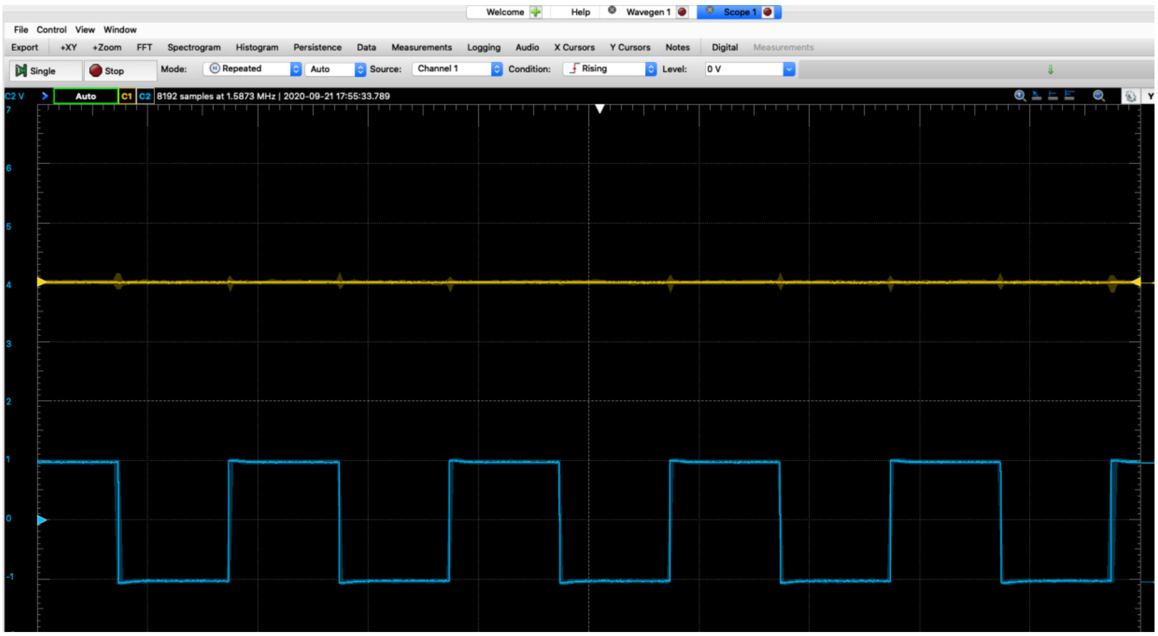
33. Click the green "run" button to generate the waveforms.



34. Once the waveforms appear as they do below, then raise your hand and say "time". If the waveforms do not appear as below, then proceed to the next step.



35. If the waveforms appear as they do below or if the waveforms appear to be moving from side to side, then lift the pin connector and wires until the waves are stable. Once the waveforms are stable then raise your hand and say “time”.



-End-

APPENDIX B. INSTITUTIONAL REVIEW BOARD APPROVAL

Date: 11-5-2020

IRB #: IRB-2020-377
Title: FCA AR Study
Creation Date: 2-28-2020
End Date:
Status: Approved
Principal Investigator: FREDERICK BERRY
Review Board: Institutional Review Board FY2021
Sponsor:

Study History

Submission Type	Initial	Review Type	Exempt	Decision	Exempt - Limited IRB
Submission Type	Modification	Review Type	Limited	Decision	Exempt - Limited IRB

Key Study Contacts

Member	Kenneth Jay	Role	Co-Principal Investigator	Contact	kjayjr@purdue.edu
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Member	FREDERICK BERRY	Role	Primary Contact	Contact	berryf@purdue.edu