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Digitizing Work Instructions Through Technology using Internet of Things (IoT)

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Dedication

I would like to dedicate this thesis work to my parents, Silvia & Jesus, who gave everything to ensure I would have the opportunity of an education. They have always been by my side, believing in me no matter what. Thank you for never letting go of me and for always pushing me when I wanted to give up.

To my sister Odalys who was always encouraging me to continue with this process and for giving her support even on tough days.

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To my professor Dr. Amit Lopes for guiding and mentoring me during this process and for sharing his expertise and time.

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by

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Abstract

Smart manufacturing is fundamentally changing the industry so fast; for this reason, modern industrial processes must be intelligently and digitally automated. Digitalization of work instructions has taken an important role in improving the efficiency of industry and traditional manufacturing processes. TULIP is a frontline operations platform that allows users to digitize operations using friendly apps that operators can deploy in their daily shopfloor processes. This Industry 4.0 tool is important because it optimizes the development of processes by enabling IoT with the use of sensors, connectors, and machines to collect real-time production data.

In this research, a manufacturing station equipped with a collaborative robot was chosen to digitize work instruction processes with the implementation of TULIP software to simulate a real manufacturing scenario. The approach consists in allowing operators/users to follow a guided program instruction that will reduce time and human error, as well as improve the way data is stored, analyzed, processed, collected, and interpreted. Two phases were developed in this study to compare the effectiveness of digitizing instructions in a manufacturing process. In the first Phase, the time that the user takes to perform an operation using manual guidance will be measured. Next, we will compare this with the time it takes to perform the same operation but with a detailed electronic work instructions app. This work instruction (WI) app also allows the user to send notifications whenever a defect is found during the operation. In the second Phase, the app collected the operator's defects as well as analytics that show the average process cycle time and the number of completions. With the implementation of digital work instructions, workers will have the advantage of having app-based platforms to create instructions for specific tasks to communicate easily and collect real-time data.

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Chapter 1 - Introduction

Industry 4.0 is the new industrial stage in which technologies are creating techniques to provide digital solutions; it has been evolving fast and getting into new technologies in manufacturing processes. Industry 4.0, which is mainly familiar as the fourth industrial revolution, is one of the most popular subjects. Each industrial revolution contributed significantly to today's growth in unique ways. The first industrial revolution happened with the first mechanical looms, which were powered by water and steam on mechanical machinery. These replaced the agricultural sectors in the 1700s. Then, the second industrial revolution happened when electrical electricity was introduced in the 1870s and created a term known as mass production, and it depended on human capabilities to accomplish more. After that, the third industrial revolution happened when there was a rise in electronics in the 1970s. It referred to the advancement of technology from analog electronic and mechanical devices to the current digital technologies. And finally, the fourth revolution is based on the digital revolution, which in simple terms, connects people and technology[1]. This idea's core component is smart manufacturing. This new technology also works with the integration of the factory with the complete product lifecycle and supply chain activities, evolving how operators work in the industries[2]. This revolution of the industry depends on the deployment of digital technologies in order to collect data in real time and analyze it, which is the case of the software used for this research ¨Tulip¨. Also, providing the industrial system with important information on the emergence of cloud services, big data analytics, and the Internet of Things (IoT).

In this scenario of Industry 4.0, Manufacturing industries play an important role in the economy of big countries, that is why smart manufacturing is continuously growing to optimize their production processes. Therefore, digitization and automation are needed for manufacturing processes in today's industry to optimize things are reduce errors. For this reason, smart industries work with new software like Tulip to digitize their processes.

Advanced manufacturing, also known as Smart Manufacturing, is the foundation of Industry 4.0. Flexible lines automatically change manufacturing procedures for a variety of commodities and change conditions in its adaptive system. This makes it possible to improve quality, efficiency, and flexibility as well as create customized items on a big scale while using fewer resources [2]. Mass production in the companies is currently giving the opportunity to customize their production, and productivity has been increasing as a result of the industries' rapid improvements in the manufacturing processes of their use of technologies and applications [3].

Industry 4.0 covers the way for a new technological era that revolutionizes the industry value chains, production, and business models. This is done by embedding the production system technologies with intelligent production processes. Direct contact with the industrial systems is possibly made by these technologies, same that enables quick problem-solving and decision-making that is adaptable [4]. To achieve these new technologies, digitalization needs to be implemented in the common processes. There are nine technological advances that have transformed the production in the industry: Autonomous robots, simulation, horizontal and vertical integration, the industrial Internet of things, cybersecurity, The cloud, additive manufacturing, augmented reality, big data and analytics, and autonomous robots as shown in figure 1-1 [5].

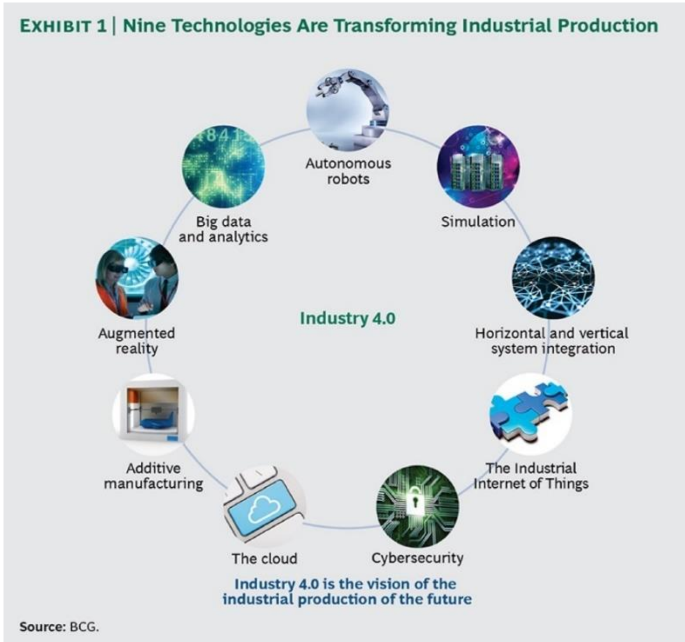

Figure 1-1: The nine pillars of technological advancement[5]

There are a lot of advantages to the use of Industry 4.0 technologies in industries. For example, it improves productivity and efficiency, increases communication and collaboration with the stakeholders of a system, enables flexibility and agility, and it reduces costs. As mentioned before, Industry 4.0 technologies enable increased flexibility and efficiency in complex assembly tasks, product design, training, quality inspection, maintenance, and logistics tasks by either facilitating these operations or by sending more information about them [6].

In the world of manufacturing, the fourth industrial transformation is happening. Its main foundation is the adoption of the Internet of Things and the creation of ideas in manufacturing factories that lead to big production systems [7].

1.1 Smart Manufacturing

Smart manufacturing over the years is a concept that has been evolving with experts, practitioners, and researchers. Many nations have addressed the necessity of modernizing their manufacturing sectors in recent years by getting the attention of digitalization, networking, and the smart intelligence of production [8]. In simple terms, smart manufacturing is a new type of manufacturing that combines today's and tomorrow's manufacturing assets with the use of sensors, computing platforms, communication technologies, control, simulation, data-intensive modeling, and predictive engineering [9]. Smart manufacturing is the digital transformation that emerges from integrating digital technology into some of the aspects of manufacturing operations and practices [10]. Because smart manufacturing meets Industry 4.0 objectives, it has become very considerable for manufacturing experts. It is a branch of Industry 4.0 in which technologies such as the digitalization of processes, computer network, database, and automation are combined to improve manufacturing experiences. This happens by using autonomous machines or robots that help develop efficient smart factories, boost production, reduce human error as well as meet customer-specific needs[11].

The purpose and strategy for getting digital data are significantly impacted by Industry 4.0 and the accompanying changes in the processes [12]. That is why companies that are implementing smart manufacturing technologies are digitizing work instructions to reduce time and reduce human errors in their manual documentation processes.

1.2 Internet of Things

The Internet of Things (IoT), often known as the Internet of Everything or the Industrial Internet, is a brand-new technological paradigm that envisions the world as a network of interconnected machines and devices[13]. The Internet of Things (IoT) is garnering considerable attention from a variety of companies and is getting to be known as one of the most significant areas of future technology. When connected devices are able to speak with one another and integrate with vendor-managed inventory systems, customer support systems, business intelligence tools, and business analytics, the true potential of the IoT for organizations may be completely realized. The idea for the Internet of Things is to integrate different technologies into everyday life, as seen in Figure 1-2, in which all of the fields that can be used for the Internet of Things, such as smart homes, everyday wearables, smart manufacturing, smart cities, transportation, agriculture, cars, health, and energy engagement to facilitate human's daily life with the IoT services [14].

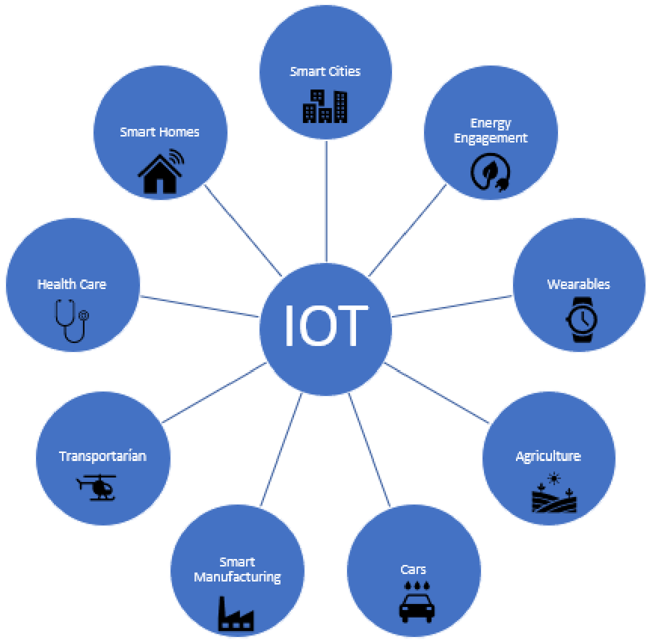

Figure 1-2 Internet of Things [14]

The Internet of Things has increased human freedom while increasing the opportunities for contact with the outside world. Global communication has been deeply influenced by the Internet of Things protocols [15]. One of the advantages of integrating IoT services into manufacturing is that it increases productivity, and it collects real-time data for your processes. Many companies are taking advantage of the Internet of Things technologies to digitize and make processes effective. One of these companies is Tulip; through this app platform, Industrial IoT and advanced analytics are made powerfully available to the manufacturing workforce. This ground-breaking self-service technology bridges the gap between manufacturing traditional systems to IT systems and their flexible operations occurring on the shop floor [16]. IoT enables the use of sensors and machines to obtain the data, and this can be accomplished by implementing software like Tulip to digitize processes and include Internet of Things technologies to collect real-time data. The way Tulip can include IoT technologies in the platform would be explained in the following section that explains the overview of the platform and how to connect with these technologies with a factory kit.

1.3 Tulip

Tulip is a frontline operations platform that connects the people, machines, devices, and systems used in a production or logistics process in a physical location. This platform allows users to create manufacturing apps to improve production in a company, serving as a secure portal that makes the user experience more friendly and more innovative for data digitization. This platform can create work instruction apps that are easy to update and with the intention to help operators do the job right the first time. Rich media, real-time ERP connections, computer vision, edge connectivity, machine integrations, and no-code logic simplifies complex tasks. It also can create guided workflows that capture data from end-users and connected devices for traceability. The platform works with different concepts that are important to define to have a better understanding throughout this paper. The word display refers in Tulip to your PC, laptop, or tablet, and on the other hand, the word device refers to an integrated device in Tulip, such as barcode scanners, calipers, cameras, etc. The following items are tools that the software contains in order to make the user's experience easier to handle:

- Apps
- Variables
- Triggers
- Stations
- Widgets
- Buttons

- Stations
- Machines
- Connectors
- Analysis/Graphs
- Tables

The platform Tulip contains a lot of tools to make your shop floor's daily operations easier to handle. Many companies are integrating this software into their daily operation processes in order to optimize their production and get good results. Some of those will be mentioned in the next point. Coming back to the IoT connectivity, Tulip supports a variety of IoT-enabled devices that can assist you in completing common manufacturing duties, including:

Capture: Capture images and videos by integrating a camera. For instance, operators can capture images of defects for review by the entire team. Using a Tulip App, the capture of an image may be a required step of a SOP, which may be reviewed during a subsequent audit.

Serialize: Utilize barcodes or RFID identifiers to serialize components. ERP/MES integrations allow you to dynamically govern the workflow within your Tulip application. Develop robust machine vision jobs that can recognize, localize, and monitor parts. Ideal for preventing errors in applications and ensuring proper component positioning. Integrate through beams, foot pedals, proximity sensors, RFID identifiers, and buttons to control the process flow. Enable hands-free operation so that operators can concentrate on their tasks.

Observe: Observe and control complex devices including CNC, injection molding, and torque drivers. Integrate operator and machine workflows with ease.

Collect information from scales, calipers, thermometers, pressure, and current sensors. Configure Tulip Triggers to dynamically control your process based on the readings of one or more sensors. Edge Devices can be viewed in Tulip's Shop Floor Tab and are associated with Stations that are either solitary or part of a Station Group [17].

Tulip provides three entry points for Internet of Things devices: obtain a Factory Kit, which is a collection of popular IoT devices and an IoT gateway that can be used together. Utilize a pre-built integration with a third-party device from Tulip's Device Library when you acquire an IoT Gateway. Utilize a USB-connectable barcode scanner or RFID reader with a Windows computer or tablet. Tulip makes it simple for manufacturers to integrate IoT device data into Tulip applications. This allows app developers to guide logic based on the output of a sensor or device. For instance, A route to the precise set of work instructions based on a work order scan. If the humidity rises above the acceptable range, the operator must stop and call for assistance. This also enables Tulip applications to capture data from IoT devices for further analysis using the Analytics Builder [18].

1.4 Tulip Use Cases

Tulip platform has been deployed along several companies to perform and track analysis like OEE (Overall Equipment Efficiency) and EdHR or work instructions to provide visual paperless guidance to help operators perform daily tasks and hard processes in a more efficient way and with fewer errors.

Taza Chocolate Factory used Tulip to bring analog machines and create real-time process visibility in its chocolate factory. Their challenge was to increase the production of chocolate by nearly 30% and, at the same time, decrease the cost of goods sold (COGS). To meet the expected goal, the company Taza needed to put a little more effort into its production processes. Here is where Tulip shows. Their result was successful by using Tulip's plug-and-play IoT connectivity[19].

Sharp Packaging is another company that is using the Tulip platform in its daily operations. Sharp plays a key role in the biotechnology and pharmaceutical industries by providing contract packaging and clinical trial supply services. Through their partnership with Berkshire Sterile Manufacturing, they offer isolator-based filling of vials, syringes, cartridges, and containers, as well as lyophilization and terminal sterilization. From Phase, I clinical trials to commercialization, their expertise in innovative technical solutions from research and development through to commercial Packaging has positioned them well to manufacture and package in multiple formats to deliver quality products [20].

1.5 UR3 Collaborative Robot

Industry 4.0 transforms advanced human-robot interaction into a crucial resource. The use of collaborative robots in modern smart factories has altered the dynamic. These robotic items can help operators to work closely to perform different activities [21]. Collaborative robots, also called cobots, are automated robots that were created to collaborate with humans in the industrial setting to make processes better and optimize productivity in companies. This type of robotic automation, known as collaborative robots, is designed to function securely alongside human workers or operators in a shared collaborative workspace. In most situations, collaborative robots handle repetitive tasks while the operators perform other types of activities or jobs [22]. Cobots are deployable collaborative robots that are affordable, secure, and versatile. This tool is making automation simpler than ever talking about mid-sized businesses. Because they assist everyone in the organization in achieving performance goals, cobots are a perfect productivity tool for almost every manufacturer[23]. Over the past five years, there has been a significant expansion in the use of human-robot collaboration systems in industrial settings. From digital simulations to actual automobile assembly lines to manufacturing applications replicated in lab settings [24].

The use of a collaborative robot from the University of Texas at El Paso, like the one illustrated in Figure 1-3, will be used in this experiment to create work instructions/training for new users utilizing the Robot in a work instructions application with the platform Tulip. The idea is to allow operators to run a pre-created program of a simple pick and place path by following the WI instructions application and save their data of completions and time.

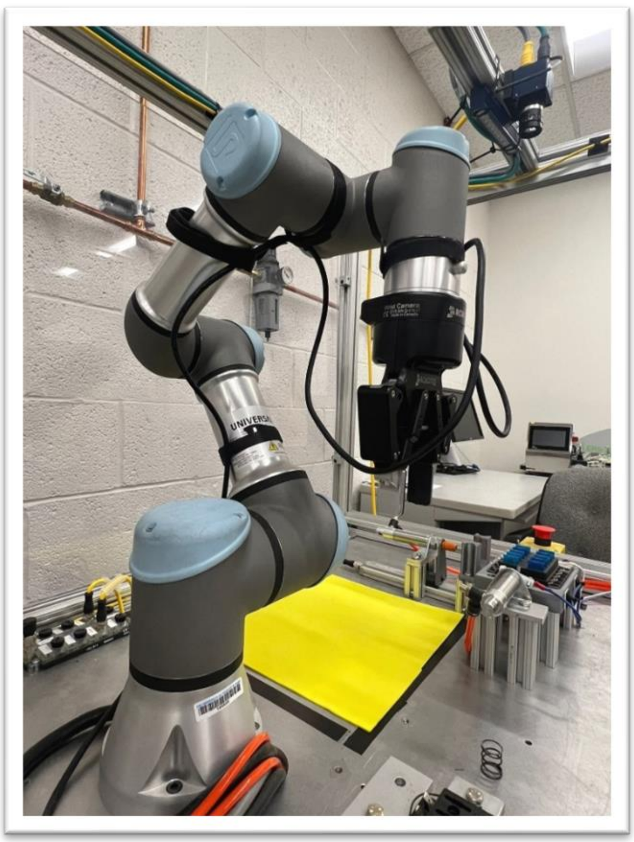

Figure 1-3 UR3 Collaborative Robot

Collaborative robots can do repetitive activities like inspections, picking and placing things, and many other things, while collaborating securely with the human operators on jobs that need teamwork. The operator is replaced as a result of giving him more time to apply his knowledge and skills to other tasks. In order to carry out safe, collaborative work with people, collaborative robots work with sensors and actuators that can be moved at the correct speed, control their force, and stay away from items or obstacles[25].

1.6 Digitizing Work Instructions

Modern work is being influenced by new technologies, which are changing how people see how labor is being organized and designed [26]. The number of ways assistance information reaches human operators in assembly workspaces has risen with the use of digital systems in manufacturing. Eventually, there is a need for more effective ways to provide recommendations for help or instructions as the production environment becomes more flexible and the jobs are changing more quickly [27]. For this reason, industrial innovation is under pressure to preserve and enhance the competitiveness of their production systems. An example of this process to increase the optimization potential is the use of digitalization of work instructions. Human operators are frequently required to have the necessary knowledge and skills to carry out industrial job duties, such as assembly or maintenance. The use of work instructions when performing their duties helps the operators to achieve and maintain high levels of work quality. Printed sheets containing step-by-step work instructions are typically used to perform their activities. Due to industry 4.0 increasing deployment, such as intelligent automation, new technological possibilities are getting accessible for industrial operations [28].

Companies must be able to combine the use of both the latest and the available technologies in order to implement new technologies coming from the industry 4.0 principles. Modern factories are growing more and more dependent on the adoption of digitization and the development of intelligent production processes. That is why it is critical for businesses to be aware of current development trends when using them [29].

Work instructions are important pieces of information in a company. They explain to the workers what actions need to be performed and what to do next in their daily operations. But paper-based work instructions are now considered to be old-fashioned and tedious because they require corrections and revision all the time. It is more practical to digitize these instructions and collect the data in a visual and interactive way, despite the fact that, in this case, the apps can be created more accurately by an expert and reduce errors. This is because digital work instructions must be created and designed to make the operators succeed in their daily activities.

1.7 Thesis Purpose and Contribution

The purpose of this research is to learn how to make use of and take advantage of the new smart manufacturing tools such as Tulip for this 4.0 technology. The implementation of these new tools will help to optimize processes and reduce human errors in traditional work instructions processes. Traditional methods used for manufacturing processes used when creating instructions require a lot of input, time, and money. This is because operators need expertise matter while operating hard tasks such as with the programming of the collaborative Robot. But with the correct creation of applications containing work instructions, that expertise matter would be needed the whole time. Originally the process for learning how to operate the UR3 collaborative robot arm was to either consult someone, which can be time-consuming, having to find help and also because the person would not always be available to help. The operator needs to know how to operate the station and learn the basic learning from it or to do research on different websites and videos to start programming.

With the use of platforms and these new technologies such as Tulip, users will benefit from time and data collection, as will be shown in the next chapters.

For terms of this research, an experimentation of a single work instructions application was used to test the way a person with no knowledge of the collaborative Robot can perform a pick and place pre-programmed program.

Chapter 2 explains the methodology used to create the work instructions application. This chapter includes an overview of all of the components used for the creation of the Work Instructions application and an explanation that works for the app and for other app creations in general. Also, once all the components are fully explained, the next section contains the steps created for the application and how it works to perform its final purpose, which will be explained later in this paper.

Chapter 3 includes the results presented in this research, based on analytics given in the software and divided into the different results given.

Chapter 4 shows the final conclusion as well as any discussions made based on the results of this experimentation with the creation of the Work Instructions application.

Lastly, chapter 5 shows a future work suggestion for the use of Tulip software and the creation of these manufacturing applications as well as getting a connection with the UR3 Collaborative Robot.

Chapter 2 – Methodology

The platform Tulip is a platform equipped to allow the user to create applications for a real company scenario depending on its specific needs. As mentioned before, industry 4.0 is growing fast, and digitally transforming operations for smart factories situations makes their goals be accomplished better. The importance of digitizing work instructions is the friendly use and the coherence of the data provided throughout the process. Digital work instructions provide different benefits such as improvement of productivity, reduction of training time, reduction of errors, up-to-date data, and many others.

In this setting, a work instructions app would be used to allow the operator to run a UR3 collaborative robot to simulate a real manufacturing task process with a pre-created pick-and-place program. The steps for the creation from scratch of this application and the use of the application, once it has been created, will be shown in the continuation of this chapter 2.

2.1 App Building

2.1.1 Setup

Building an app with Tulip can be hard the first time, but once the main elements are clear, apps are easy to create. The application created combines UI design, conditional logic and functions, data and databases, analytics, devices, and tables. This manufacturing software is a no-code platform that has the tools necessary for creating the application to run a pre-created program for a station with a UR3 Collaborative Robot like the one illustrated in Figure 2-1 used at The

University of Texas at El Paso. The process of app creation will be explained in the continuation of this paper.

Figure 2-1 UR3 Robot Station

2.1.2 New App Creation

First, we will have to navigate to the apps page in the main tulip instance, as shown in Figure 2-2. Once the apps button has been selected, on this page, you can see the apps you have already created as well as app groups and folders that can organize your applications in the order or naming that you desire. This Apps button beside Apps contains features such as Tables, Connectors, tools that can also be used once the app is created. Later, in the continuation of this paper, the portion of a table will be explained for the purposes of this application.

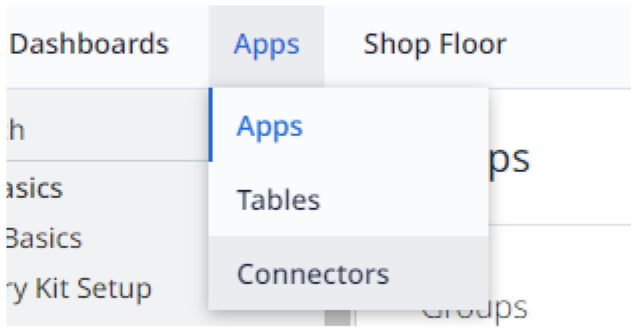

Figure 2-2 Apps Tab

After selecting the Apps tab, all the applications created before will be shown. Two options are available for this step, either creating a new app or selecting an existing one. For purposes of this paper, we will select +Create App, as it is illustrated in Figure 2-3, to look at the step-by-step guide for the Running a UR3 Robot Work Instructions. Now the option for the app information will be prompted where the name of the app and a description is needed to proceed. Adding a name and a description of the new application is important and very helpful in tracking the app and what is needed.

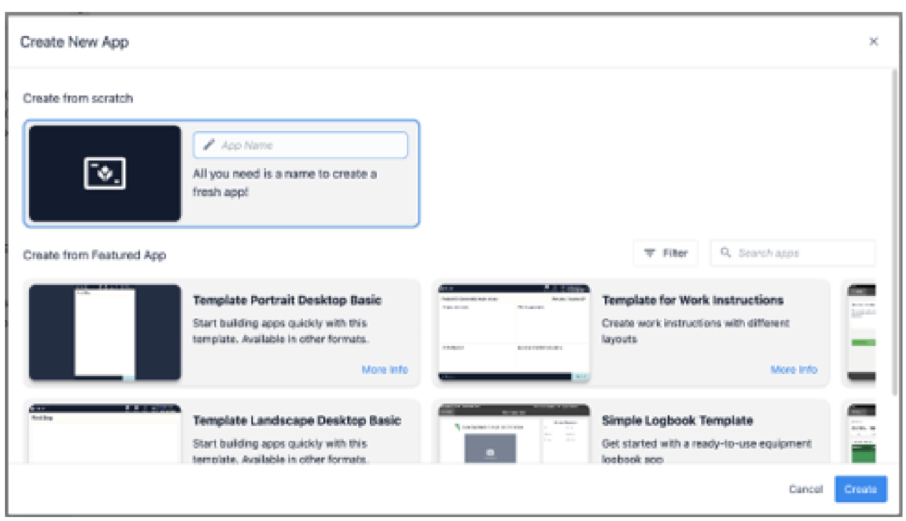

Figure 2-3 Create New App

Then, after adding the name and the description of the application, the next thing to do is click the "Edit" Button located at the top-right corner, as it is shown in Figure 2-4, or also click directly on the step button to start adding a format and the desired design to the application.

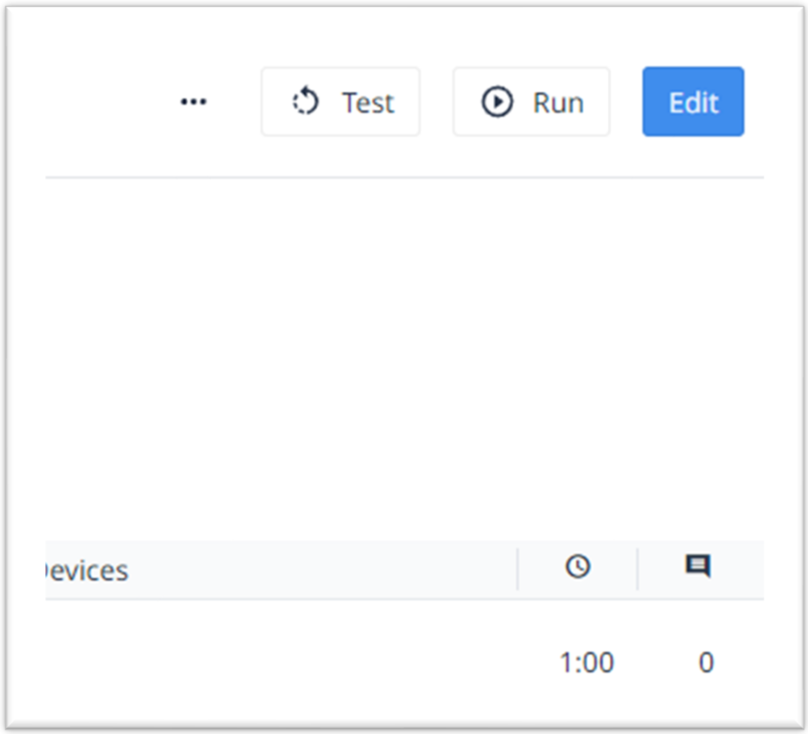

Figure 2-4 Edit Button

The edit tab will enable the user to add features to the application and provide a layout that meets the requirements of the application that is being created. As previously stated, the application may contain modifiable elements such as buttons, triggers, steps, tables, devices, and assets, among others.

2.2 App Editor

This is the important part of the creation of the application; here is where the app is built and edited, in other words, where the app will take form and have a good look when prompted to the device. In the following diagram shown in Figure 2-5 [30], the different components of the app editor are labeled with a numeration from 1 through 16. Each label represents a component of the app editor, where the application will take shape due to the editor's various tools. Each designated number is then explained in detail, including its function and operation.

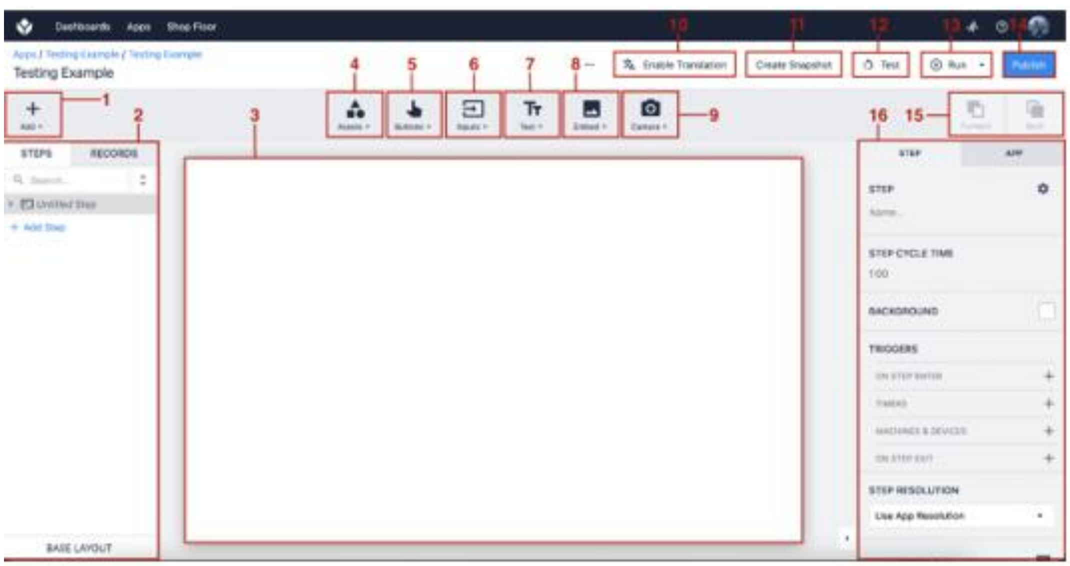

Figure 2-5 App Layout[30].

1. <u>Add Step/Step Group</u> Button that allows the user to add a new step or a Step Group.
2. <u>Step/Records Panel</u> Place to view steps, viewing records tab where tables used in the app are. Also, the base layout tab is where the main layout of the application is.
3. <u>Workspace</u> This is the place to create the app interface.

4. Add an Asset Widget Building block to display elements like shapes, icons, or logos to the application.

5. Add a Button Widget Building block that allows adding buttons to the app that displays text and can trigger an action. Contains buttons like Button (can be configured with any logic), Previous (Allows to go to the last step the user was on), Menu (Button that allows the user to change the app, change the language, log out from the application that is in use, pause the app), Next (Button that allows the user to jump to the next app step), Complete (Button that allows the user to execute the completion of the application or the step, this Button can store the app variables to later create analytics). Figure 2-6 illustrates the buttons portion that was explained previously.

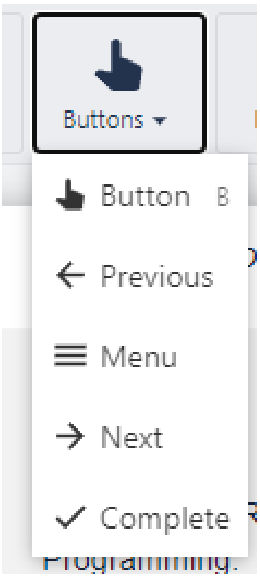

Figure 2-6 Buttons

6. Add an Input Widget Building block that can add an input field to the application; each of the inputs can collect data by storing the information into variables or fields in the table records.
7. Add a Text Widget Building block that can add a text box to the app. This widget can display static or dynamic text stored in table records by the use of variables.
8. Embed a Widget Building block that can embed various widgets like images, analyses, machine attributes, and others. This feature can display dynamic analytics for the application and show machine attributes or interactive tables that show the representations of the production view.
9. Add Camera Widget Feature that allows the user to add a regular camera or a barcode camera snapshot and display tulip vision for the apps.
10. Translate Button that allows the user to select a language and translate it automatically into the selected language.
11. Create Snapshot à This feature from Tulip saves the current version of the app created, and it duplicates the app so it can be tested multiple times, but with no need to edit the previous version. Snapshot is a powerful tool to save development if the app is not ready to deploy.
12. Test à This Button is very helpful because it allows the user to test the application in the developer mode, which is the interface dedicated to test all of the actions made in the app with the exception of table filling and app completions, which will appear when you run the app.
13. Run Button that, when selected, will launch the Tulip Player when installed and will run the application in production. The tulip player can also be run in a browser.
14. Publish Button for publishing an application.

15. <u>Forward/Back à </u>Buttons that can move an element in the workspace where your app format is either forward or behind other elements in the application.
16. <u>Trigger Panel à </u>Space where triggers (triggers are the way or mechanism for tulip apps to do things, triggers can store data, move the user between steps, and many more) of the application can be set along with stylistic elements and add app-level information.

Following an explanation of the tulip editor and the various components that make it up, the steps portion of the application will now be broken down in detail so that the various components and the process of developing each step can be comprehended.

2.3 Steps

Steps are the body of the application; they can be set up in a variety of ways to present various content to operators. It is important to note that users are not required to proceed through the stages in the specified order. Users can progress through the phases in any sequence by using triggers. Each step may contain its own independent set of automated logic [31].

The app editor works to allow the creation of the application with a series of steps useful for the operator. The same can be arranged within groups to make the app more organized. Steps are the main "pages" of the app [30], where the content will be displayed for the operator to use. To create a new step, simply go to the top left corner and click on the Add Step button. The following window shown in Figure 2-7 will be prompted to select one of the options. Here is where the steps of the work instructions will be added, starting with the introduction of how the application will work.

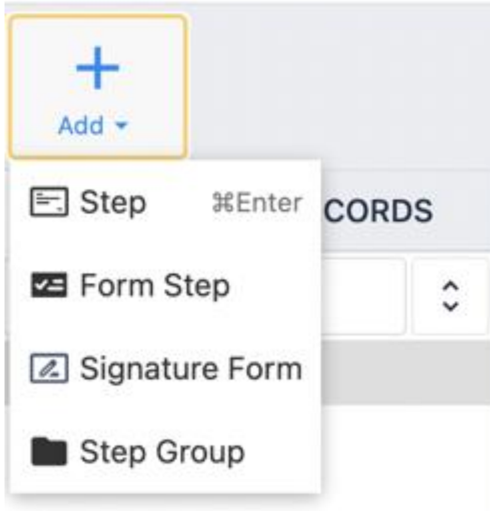

Figure 2-7 Steps

There are types of steps that can be used within the application, and each type contains different characteristics to adjust accordingly to the path desired. It is important to name every step according to what is happening on the application so that the operator or the user that is making use of the application has a sense of what is happening at the moment and avoids confusion while running the app.

Step: is the regular Button to create new content on the application; this can be customized according to every need using widgets.

Form Step: this is the feature that allows the use of forms for the user or operator to input details about the work that is being performed. This is commonly used to substitute checkboxes for common defect reports and add comments about the defect. For purposes of this research, form steps will be used for the operator to notify and record any failure with the use of the Robot, as it is shown in Figure 2-8. The step form contains a space for typing the same ID that needs to be filled for terms of records with 00 followed by the current date that the defect was reported. Next, a space to describe what is happening with the defect so that the engineer has an idea of what defect was found and get a solution. The defect form also contains two boolean questions that are based on the limitations of the Robot running. Are fixtures well placed? If they are not, the engineer will have a sense of this and ask to properly place them so the Robot accomplishes its journey satisfactorily. Was the red Button released? If the buttons were not released at the beginning, this could cause an issue, and the engineer would ask to release them so that the Robot can run accordingly. These types of forms allow the user or the engineer to notice constant defects and store the information with the use of triggers.

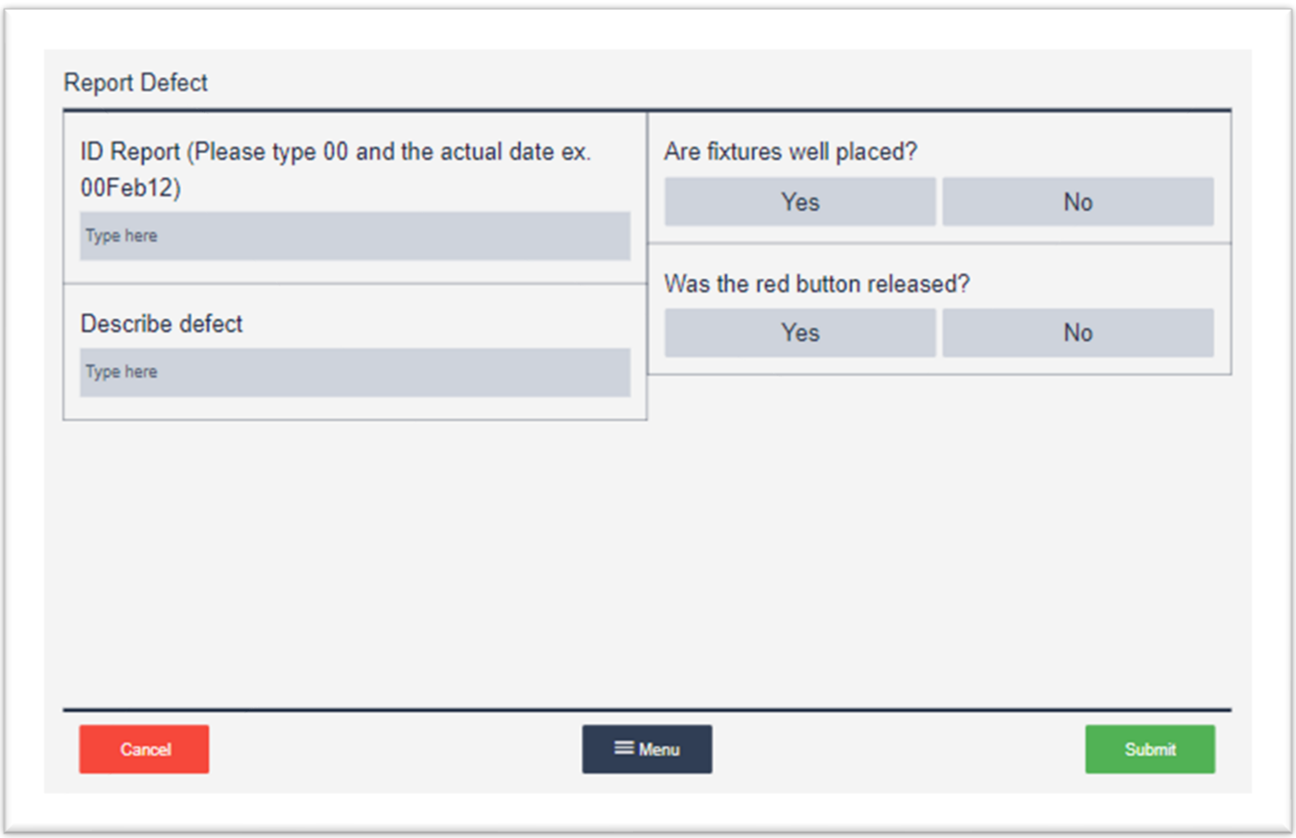

Figure 2-8 Defect Form

There are various options for step forms to display the information to be filled in, as Figure 2-9 illustrates. Forms can replace common manual defect forms and help to store the information when defects are reported.

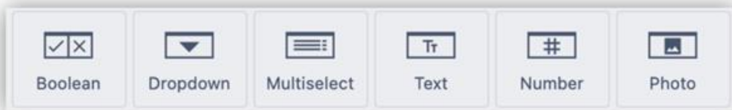

Figure 2-9 Form Options

- The Boolean option works to select a default value for a yes or no question. For purposes of the UR3 Work Instructions application, Boolean-type questions are used, as explained before, to delimit if actions were performed correctly. Otherwise, the Robot will fail to complete the regular operations.
- The Dropdown option for the step form lets to choose an option that needs to be selected by default. When this widget is added to the form step, a list of options will be provided to the user to select one from the list previously added. The following dropdown options will be added to the list as common defect parts from the UR3. (Add parts from the list). To add new values to the list, go to the + Button and add the individual options for the dropdown list.
- The multi-select option allows the user to pick several options from the list provided.
- The text widget works to type text; it adds a single line for the user to add longer responses. We used this widget for the operator to add any comments. If the Robot has a defect, it asks to describe, if possible, the details of the defect so the technician knows what is happening and fix it.

- The number widget allows the user to type a number and use plus or minus sign to increment or decrease the value input.
- Lastly, the photo widget can take a picture with the device's camera that is being used and loaded to the record of the step form. The user will upload a picture of the defect from the Robot so an analysis can be created after. This option also permits the user to add an existing picture from the device that's being used, but here, the user will have to upload a picture of the collaborative Robot having a defect [32].

Continuing with the steps portion, also signature form is another component of this window that allows the creator to require the user or operators to add a signature when they finish filling out a form. This will ensure the authenticity of who is sending the report form and confirms the completion. Lastly, step groups work to accommodate and organize steps into folders to perform bulk operations. It is important to add logic to your transition steps so that the user finds it easy to transition and it's easy to store.

For the steps to make sense, triggers are required to execute the intended actions. Once the UI design has been created, the actions necessary for the app to function are executed by triggers.

2.4 Triggers

Triggers play a very important role in the development of your application. Without the use of triggers, your app would be a flat screen with a simple format and buttons with no actions. In other words, triggers make your app do actions to do something. Triggers can store data, move the users between steps, interface with other software, connect with machines, and perform many other actions. Also, triggers are presented in three ways to give logic to the action you want to accomplish. First, "button triggers" are the action activated when the Button is pressed. This means that a certain action would be performed when the operator presses the Button. Second, step-level triggers are actions that can be set with each app step. The step-level triggers are configured based on four actions which are: when the step is opened, every amount of time (x seconds), when a machine out device has an output of data, or when the step is exited. Third and lastly is the app-level triggers which are actions that are configured for each of the apps: when the app is started, when the app is canceled, and when the app is completed.

Triggers features are located at the right side of the tulip's editor; when you click on the Button, the action needs to be as Figure 2-10 illustrates. Simply go to the step tab and select the trigger wanted by clicking on the plus sign.

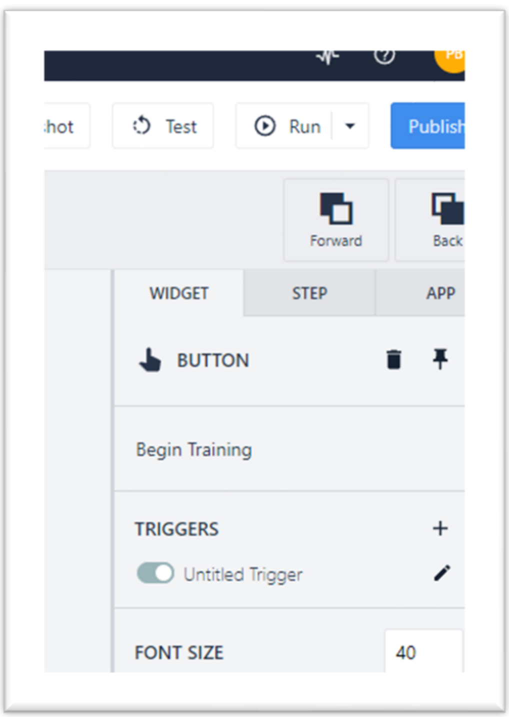

Figure 2-10 Untitled Trigger

Triggers can sound complicated, but they all follow the same format to give an action to your widgets. The legend they follow, according to Tulip's knowledge base, is: "When an action happens, then perform the following action and/or transition¨. As mentioned before, triggers are those pieces of tools that will allow you to take action. This can be simple or complicated, depending on what you want to obtain.

If statements are conditions that you set for the next action to happen. Then statements can be divided in two: action or transition, and can perform the actions selected, as Figure 2-11 shows. An action is more of a change in the application; this means that it is not related to the change in the steps. And on the other hand, the transition changes between steps, or it does complete the app.

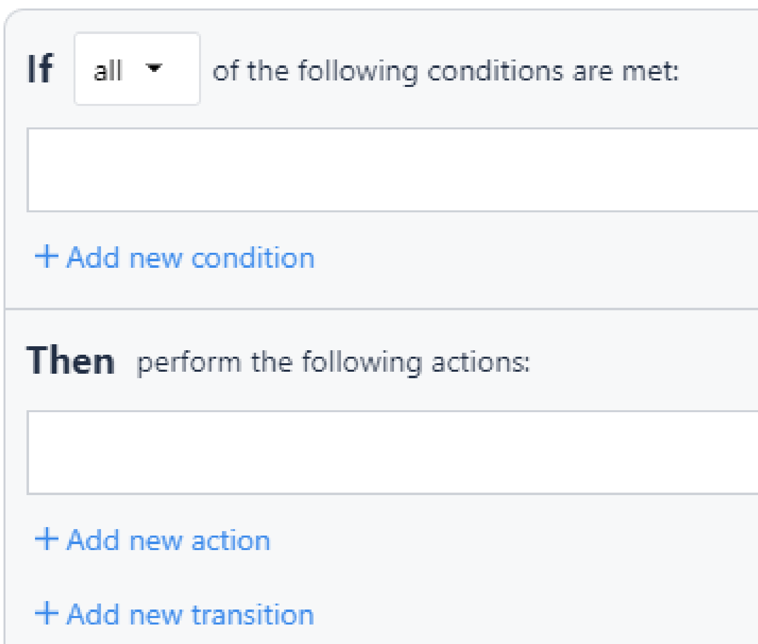

Figure 2-11 Trigger Structure

2.4.1 Triggers Use

This research work instructions app works with several triggers in order to perform the action wanted. A trigger for completing the app would be used to log the data when the operator finishes running the WI app. Another trigger is used for all of the steps, like the one shown in Figure 2-12. This trigger allows the operator to change between steps by just clicking on the next Button. If we continue with the triggers, another one is used for sending an alert. This could be an email to the technician if the UR3 robot has a defect. Storing data is another trigger that will store the user's completion progress and defect report form that the operators will send if the action has an issue.

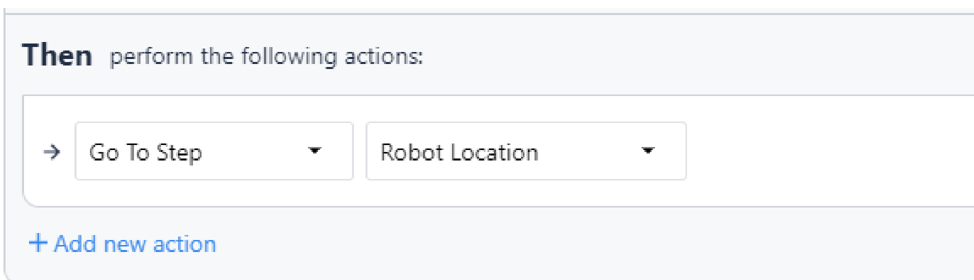

Figure 2-12 Next Step Trigger

2.5 Variables

Variables, same as triggers, are also another important component for this platform and the creation of the application. They are the types of data that will be stored in Tulip that can be used later for tables and analytics. The importance of using variables within your app is because this tool allows the creator to store the input data of the user into tables that can be later downloaded and used to create analytics, as previously mentioned. Variables come in different values such as Boolean, color, datetime, text, file image, integer, interval, number, machine, object, user, and stations[33]. As mentioned before, this type of value can store the information of the app and keep it on tables and analytics. Figure 2-13 shows an example of some of the variables from the app step portion used in the work instructions application.

The variables used for this app are used in the report defect form that will be shown later in this paper. There are number, text, and Boolean-based variables that would store the data of the user in a table called "Report Defect," which will be explained later. All of the variables can be stored in tables and can be used for any application if you need to store data such as user completions, the input of values, logged-in users, numbers, and many others.

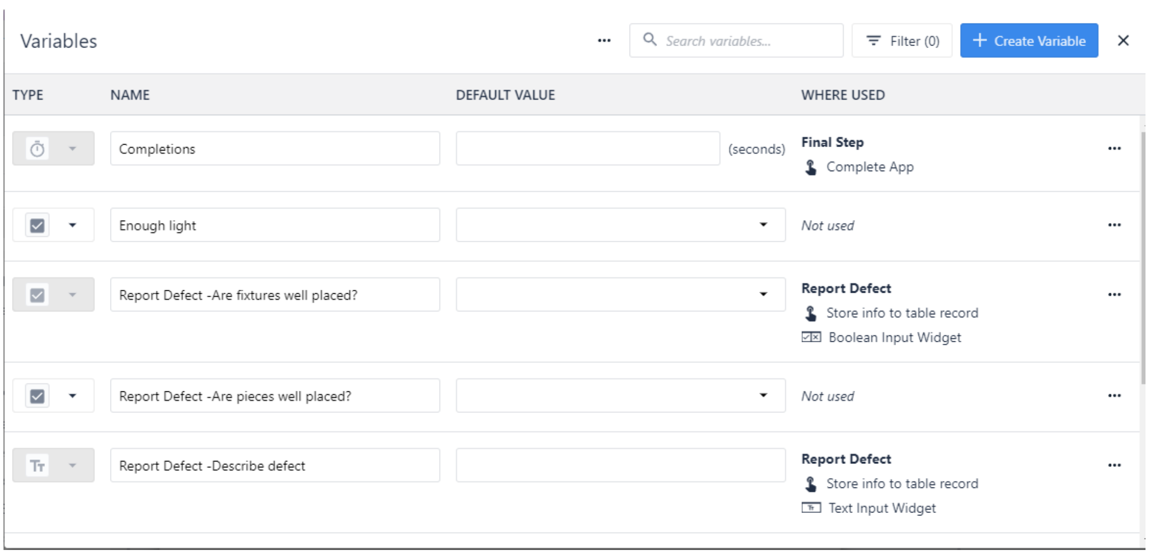

Figure 2-13 Variables

Variables can be named accordingly to what is happening in the action you want to store, but they must be unique for the use of your application. It can be abbreviations and also can describe the action that would store the data. For example, for this application, the variables used to store the data from the report form that will store the information into a table has the following naming and types of variables: Add names of variables and types Completions variable, named completions.

2.6 Tables

Tulip tables serve as a global repository for production data. Tables consist of Records (rows). A single can be accessed simultaneously from multiple applications or stations. In contrast to Variables, which can only be used to monitor data within a single app, Tables enable the use of data across multiple apps. Each Table resembles an Excel spreadsheet or SQL table. Every row in the Table is referred to as a Record, and all fields that you add to a Record will naturally be included. Each record must have a unique ID value which will be explained next. This enables you to load a record's surrounding data into an application. Tables may contain no more than 200 fields, which includes previously deleted fields. Therefore, if 20 fields were deleted in the past, the Table can contain up to 180 fields [34]. Tables same, as the other tools in this software, are another useful feature that can be used to keep information in place and create analytics as well.

2.6.1 Tables Setting

To get access to the portion of the Table, you may locate the Apps section and select Tables, as it is shown in Figure 2-14.

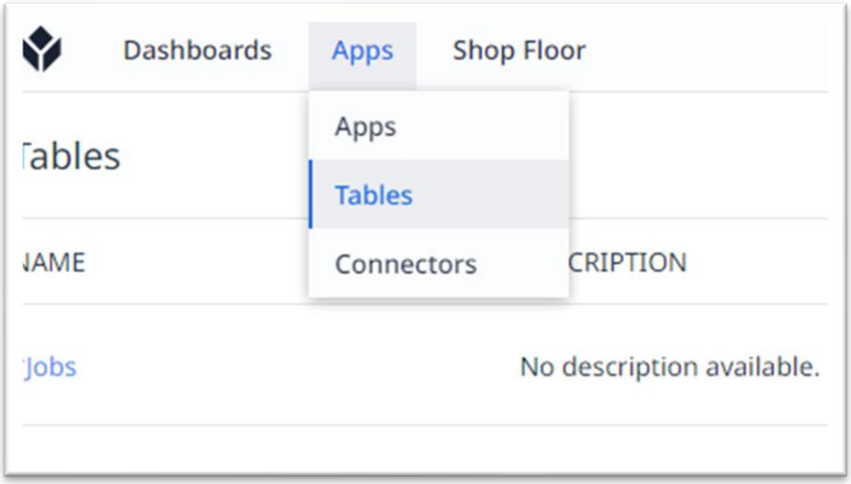

Figure 2-14 Location of Tables Section

On the screen that appears as a result, in the upper right-hand corner of the screen, you will see a button that allows you to either create a table or archive an existing table by clicking on the trashcan icon that is located next to the Table in question as Figure 2-15. You can also view a list of the applications that are referred to by each Table and navigate to those applications directly from this page.

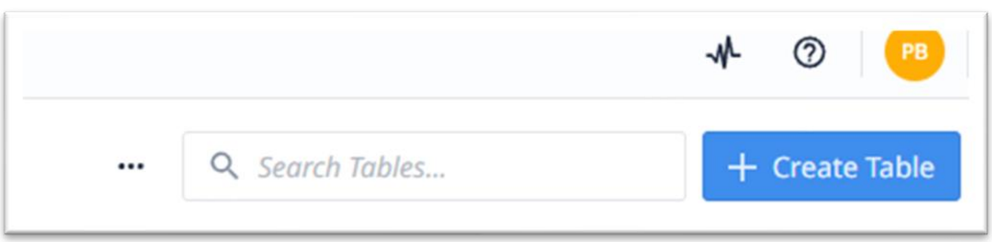

Figure 2-15 Create a New Table Screen

Once the "Create Table" is clicked, you can now add the name of the Table as well as the description that best fits the application, as it is shown in Figure 2-16.

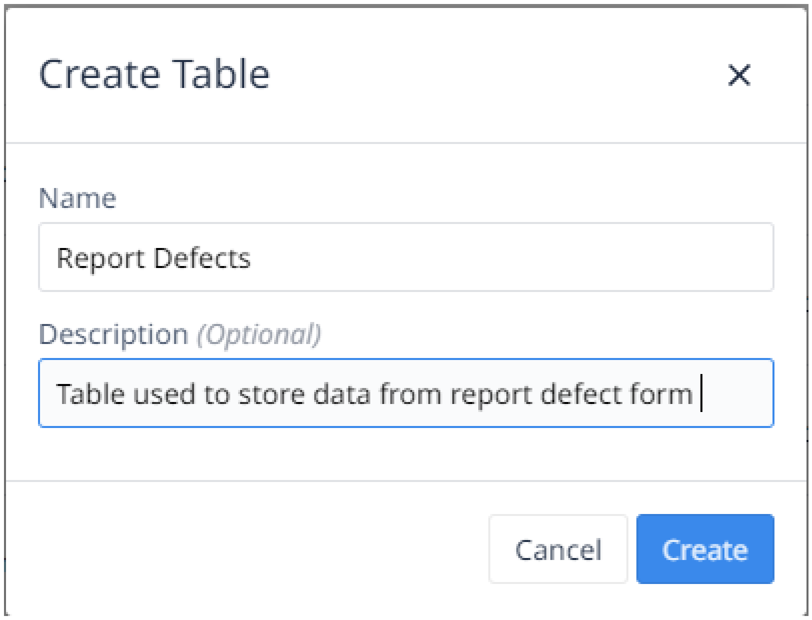

Figure 2-16 Naming Table

Select or search for the Table you just created in the Table List to begin editing. You must now begin adding Table Record Fields for all the data you wish to monitor. A Field is comparable to a spreadsheet column. To add a new field, click the plus sign beside ID. Additionally, you could add a Table Record Field by tapping the carrot next to one of the fields and selecting Insert Left or Insert Right. We can now add the fields of the Table we are creating; in total, there are 13 different field types that you can use for tables (Text, Number, Boolean, Integer, Image, Video, File, User, Datetime, Color, Linked Record, Machine, Station). Figure 2-17 illustrates the field types used for this Table. It is based on the common defects presented when running the collaborative Robot.

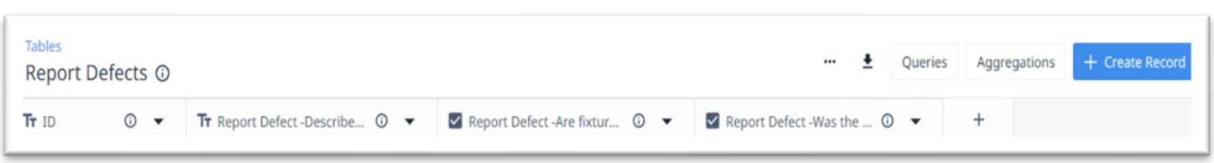

Figure 2-17 Report Defect Table Fields

Knowing the app editor's components and the many tools for creating an application, we can dive into app creation and how it is supposed to work to run a pre-programmed pick-and-place robot program.

2.7 Work Instructions App structure

The platform contains a section for the user to select the desired application to edit or look at. For purposes of this experimentation, we would select the folder containing Priscila's apps. Followed by the UR3 Instructions application, previously created to teach a user how to run an existing program of the collaborative Robot.

Figure 2.14 illustrates the way that the main apps page looks at the moment of selecting an application or creating a new one. Previously we showed how to create a new application, but once it is named, the following item will appear, indicating it is time to select the application desired. For terms of this research, the UR3 Work Instructions button would be selected to proceed with the rest of the application steps and functioning.

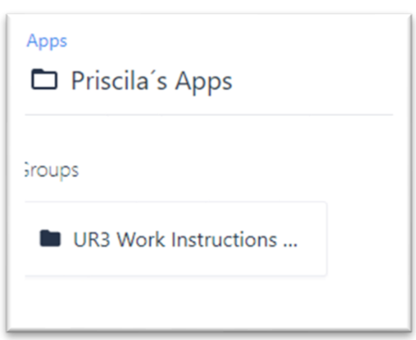

Figure 2-18 App Selection

After selecting the UR3 Work Instructions, the software will be prompted to the application, where we can see the master layout used in all of the steps of the application. The base layout shown in Figure 2-19 contains the structure followed for the steps in the work instructions application. It is a simple-looking layout that contains the information needed for the rest of the steps used in this work instructions application.

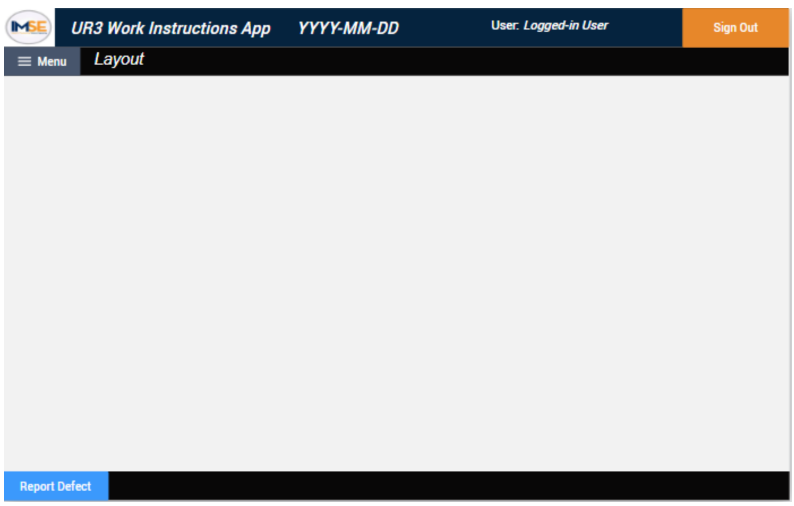

Figure 2-19 Work Instructions App Layout Base

The following illustrations show the design of the UR3 work instructions application used to run a pre-created program of a pick and place task from the collaborative Robot. First, as shown in Figure 15, the app shows important information such as the name of the application, the current date, the logged-in user, the name of the step, a button to sign out of the app, and a menu button that allows the user to either cancel the app or select a different one. This simple work instructions app begins with an introduction section where the operator knows what the application is about.

After reading the details, a green button pops up, indicating to begin the training, as shown in Figure 2-20.

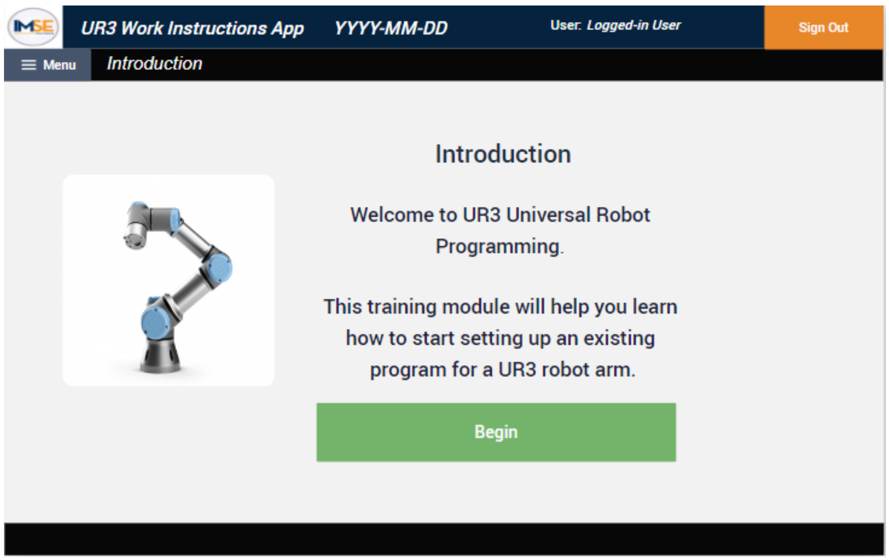

Figure 2-20 Step 1 introduction

The second step, called "Getting Help," would come next after properly clicking on the begin button from the previous step. Here the operator would have the opportunity to learn about how they can get help. It shows in a simple format the Button that is available in case they struggle with the running of the pre-created program of the collaborative Robot, as Figure 2-21 shows.

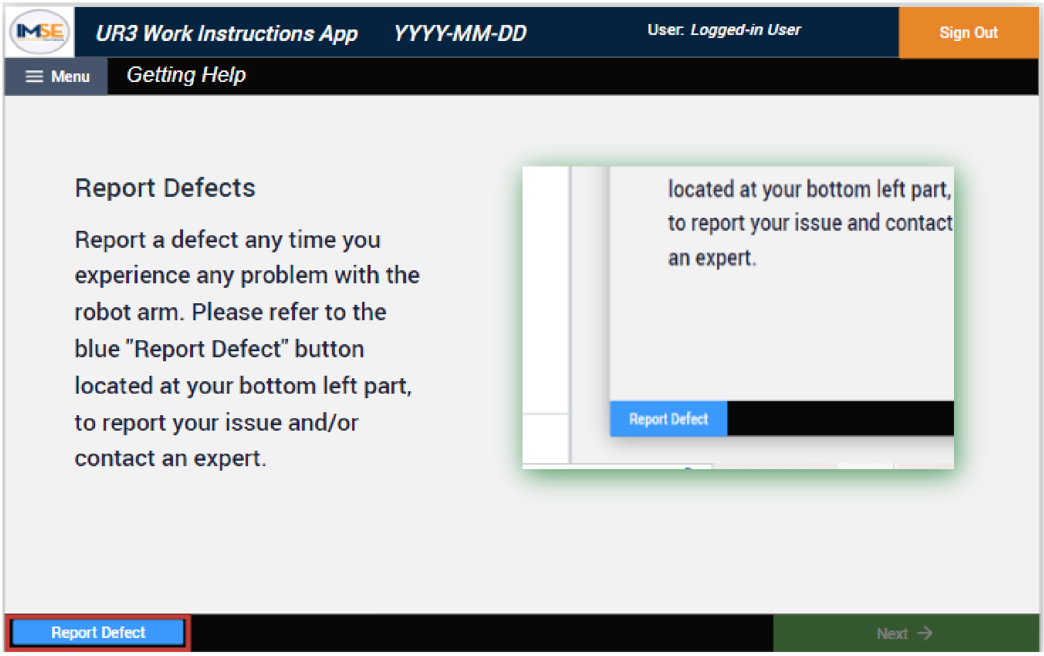

Figure 2-21 Step 2 Report Defects

After clicking on the next Button as indicated, the following step, "Defect Form Instructions," would appear, indicating to the operator the instructions to follow in case they are having a defect or an error with the Robot. The step was designed for the operator to know what to do; it shows an illustration of what a defect form looks like and the format they need to submit. As

well as an indication for an ask for help button that would allow to send a direct email to the expert with the Robot and ask for support, as shown in Figure 2-22.

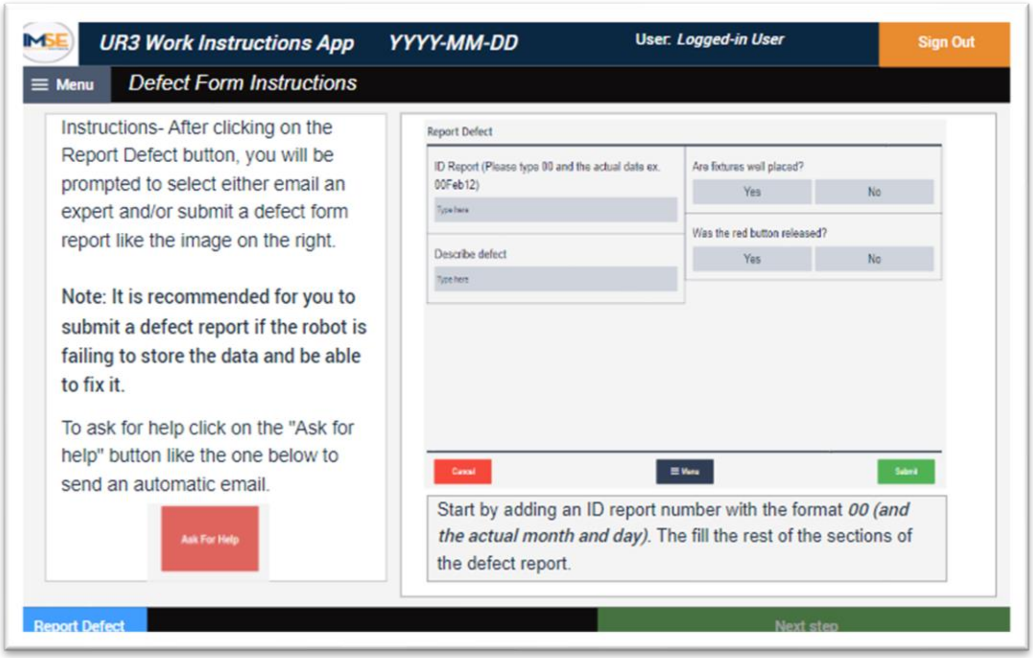

Figure 2-22 Step 3 Defect Form Instructions

After that, a comprehension check step would show a simple question to follow. These two buttons contain specific triggers that prompt an action: go to the first step of the application, or if the green Button is selected, go to the next step. According to the understanding of the operator with the previous steps, the following buttons would appear, and select the one preferred shown in Figure 2-23.

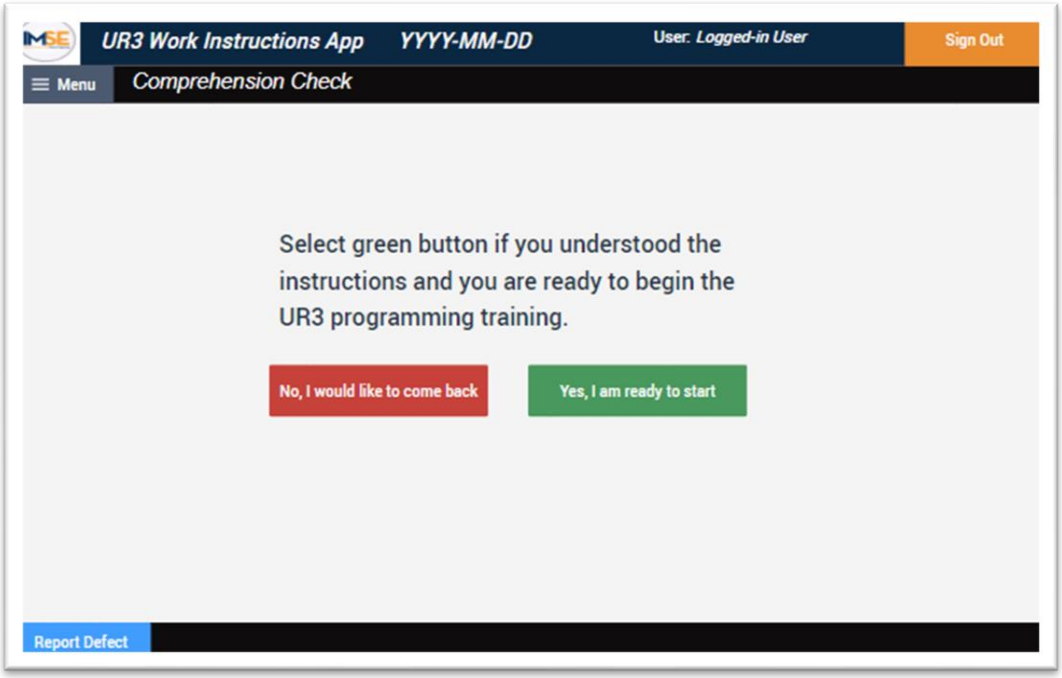

Figure 2-23 Step 4 Comprehension Check

This step, "Setting Station," was designed for the operator to pay close attention to the details before proceeding with the running of the program. It starts with a warning sign stating that the stop buttons need to be released before proceeding, as well as the fixtures need to be properly accommodated. The step window also provides a sign-out Button to cancel the application, along with a report defect button to allow the operator to ask for help and a "Go to Next Step" button, as it is shown in Figure 2-24.

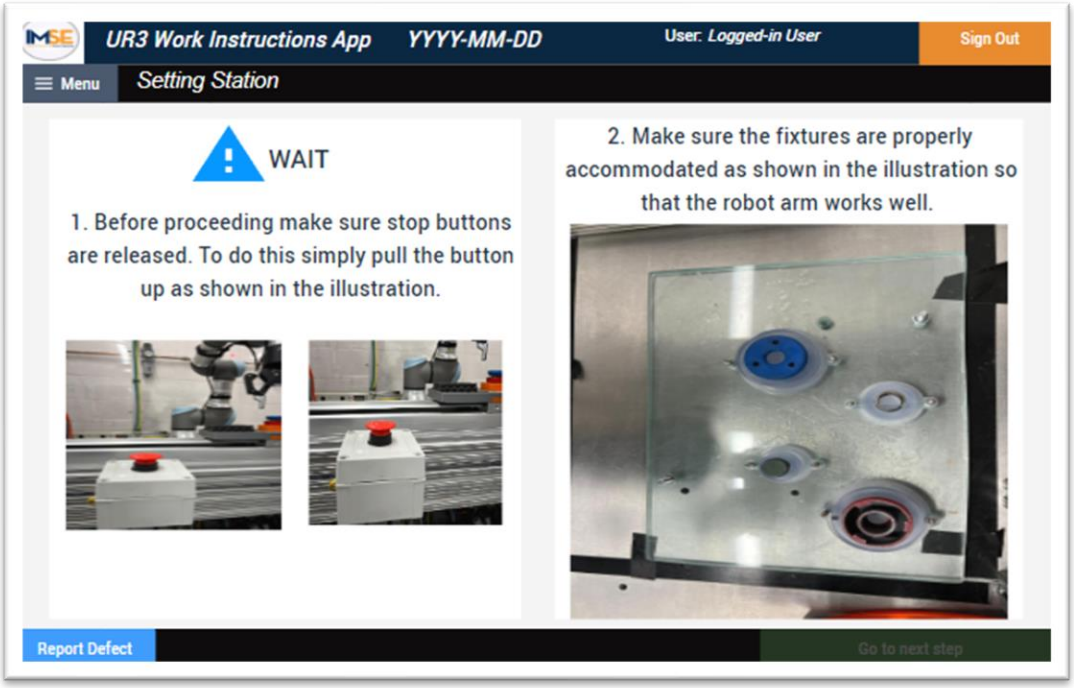

Figure 2-24 step 5 Setting Station

The "Plug In" step is the first official step to load an existing program for the Robot. It starts with easy steps on how to turn on the station from the really beginning. It is a clear instruction that contains the needed information, a report defect button in case the operator has any trouble, and a "Go to next step" button to proceed with the steps, as shown in Figure 2-25.

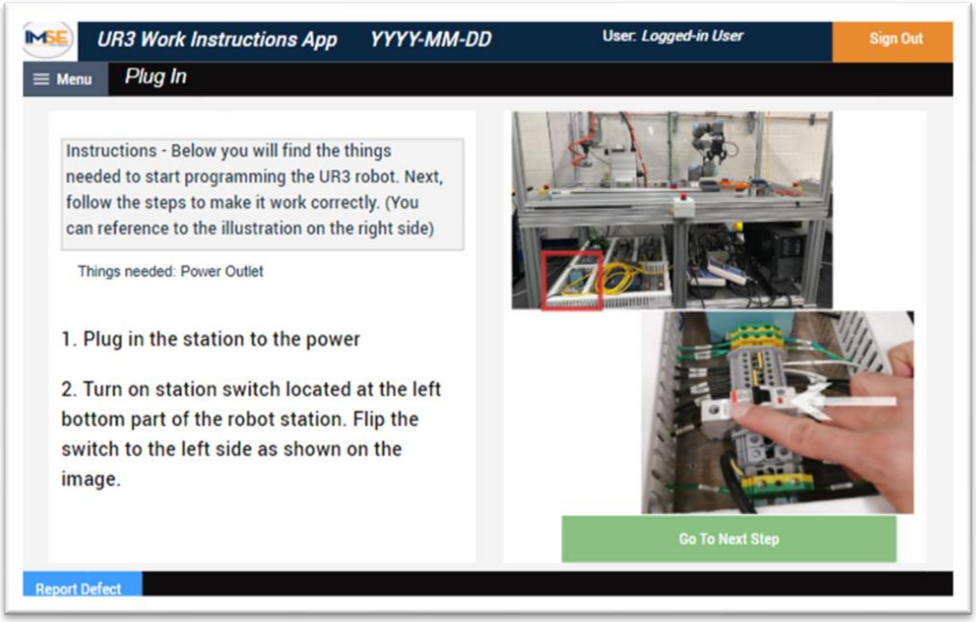

Figure 2-25 Step 6 Plugin

This next step, called "Teach Pendant," shows the operator to locate the teach pendant of the robot station, same that would allow all of the activities to be performed. Again, the step contains information such as what instructions are needed to proceed, a sign-out Button, a report defect button in case the operator needs to fill out a report defect form or send an email to an expert, and lastly, a "Go to next step" button. This Button has a set of triggers that work to let the operator or the user move to the next step by just clicking on the green Button, as it is shown in Figure 2-26.

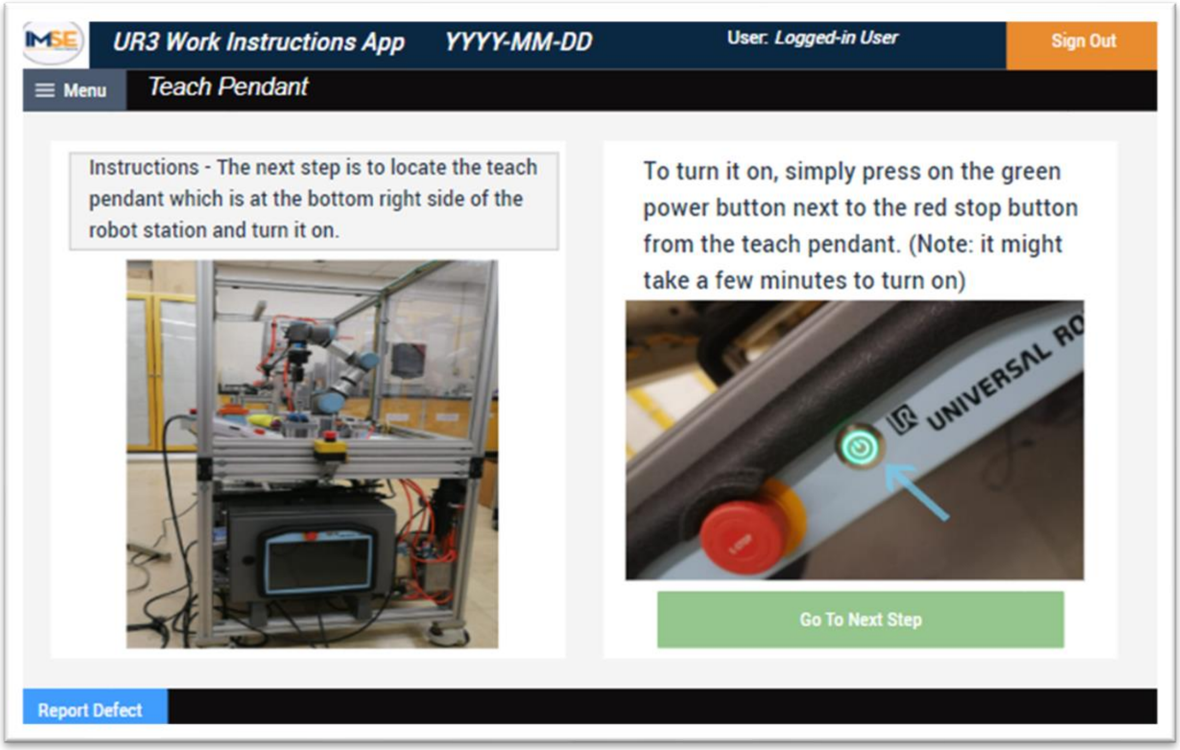

Figure 2-26 Step 7 Teach Pendant

After clicking on the green Button, a new window will appear containing the "Activate UR3 Robot" step in which the operator follows two instructions to activate the collaborative robot arm. These are simple and well-explanatory instructions that are shown with text and with illustrations. After the operator follows the steps, a green button with a "Go to Next Step" will blink to proceed, as shown in Figure 2-27.

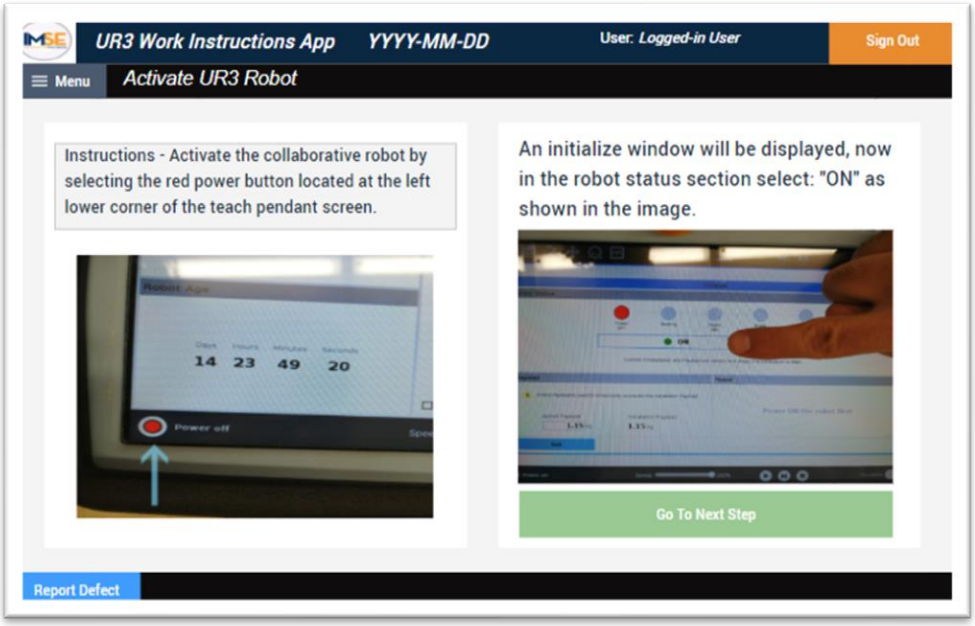

Figure 2-27 Step 8 Activate UR3 Robot

Same as the previous for this step called "Release Brake," the operator has the instructions and the illustrations needed to proceed to the next step by selecting the Go to Next step green button when the operation is complete, and it functions correctly, as shown in the illustration example as the Figure 2-28 shows. The illustrations show where the operator needs to go and select to proceed correctly. The design used for this step is intended to be user-friendly and understandable so that the operator does not have an issue with the interpretation of the step.

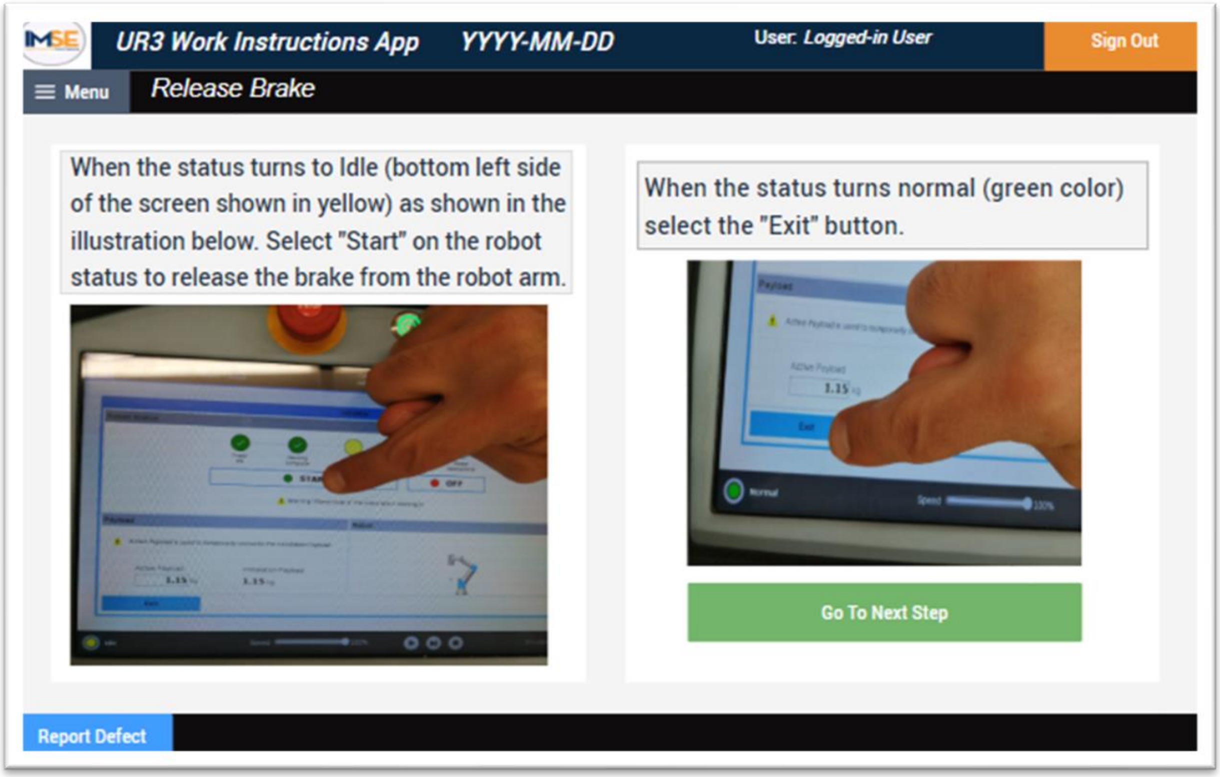

Figure 2-28 Step 9 Release Brake

The following Figure 2-29 illustrates the next step that the operator will follow to proceed with the correct functioning of the program. Again, it follows a simple, user-friendly format that indicates where to press and what to do after. Once the operators complete the task in the teach pendant, same as in the steps before, the Go to next step would be blinking to continue with the next instruction to follow.

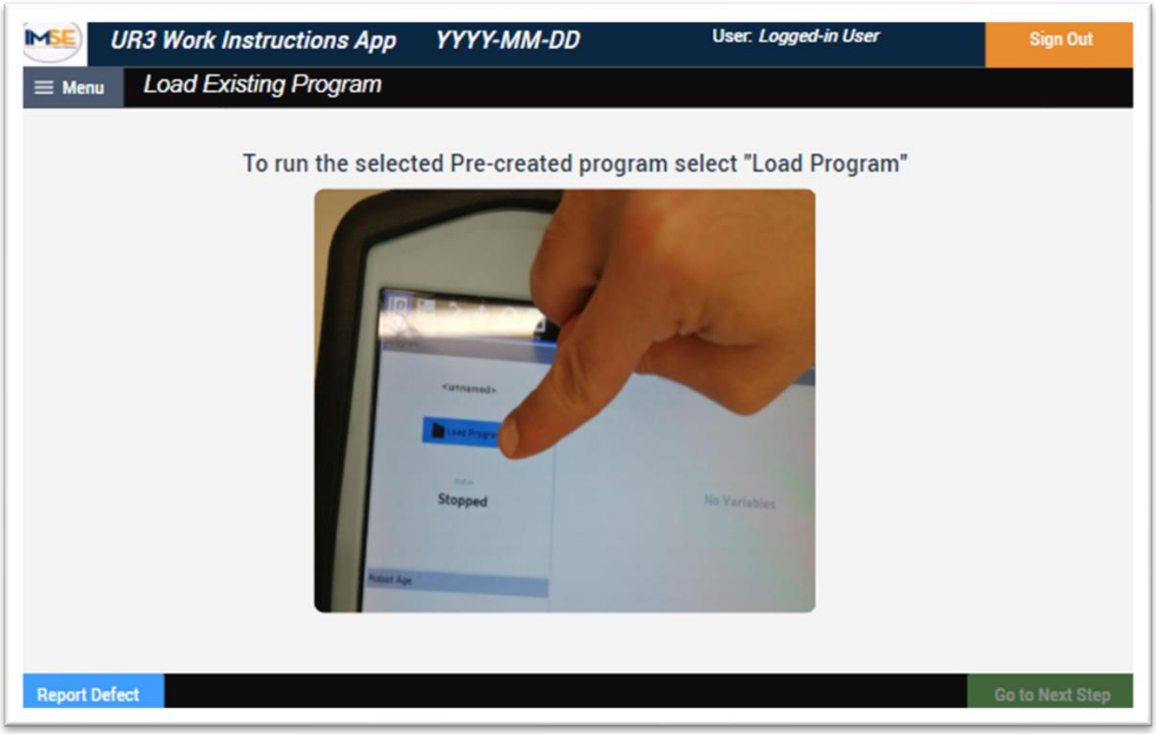

Figure 2-29 Step 10 Load Existing Program

Following the steps, Figure 2-30 shows the "Select Existing Program" instruction that needs to be done to add a pre-programmed file and make the UR3 Collaborative Robot make some movements with the selected program, which is under the Asif Khan folder and continued by the name of "demo_002-Fixtures_01.urp which performs a simple pick and place task for the fixtures previously placed in Figure 19.

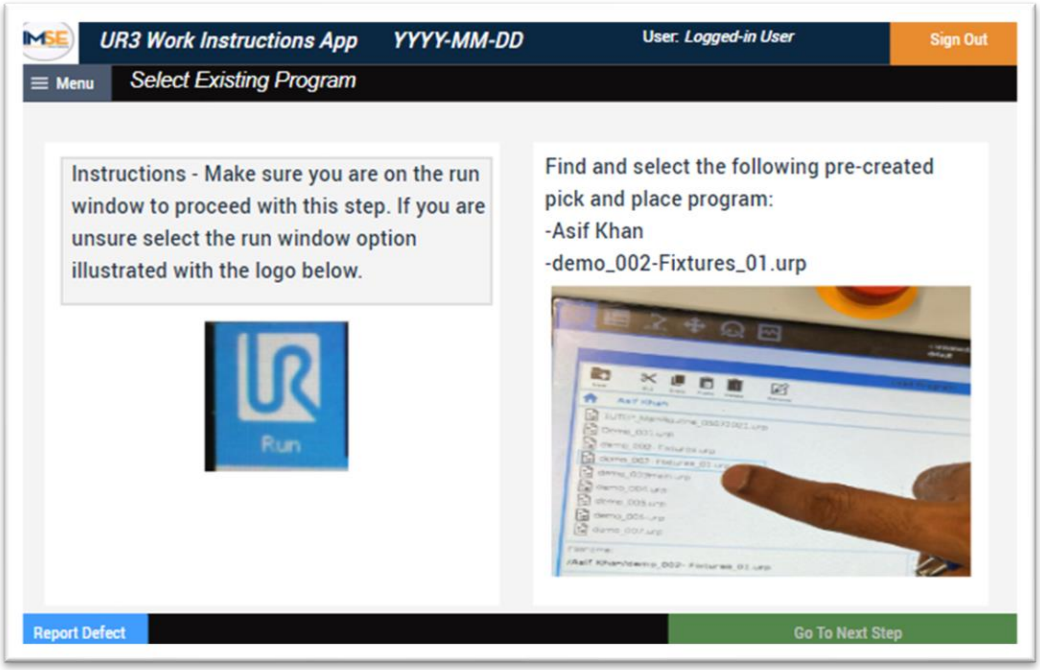

Figure 2-30 Step 11 Select Existing Program

Figure 2-31 shows the "Run Existing Program" step window. The step is the same as the previous ones. It contains simple written instructions for the operator to follow along with illustrations that help to understand the context better. Also, the step app window contains the relevant information such as the name of the app, current date, a sign-out Button, a menu button, a report defect button that allows the user to report a defect and send an email to ask for assistance at any point, and lastly a green Go to Next Button that allows the operator to record the understanding of the current step and proceed with the next one.

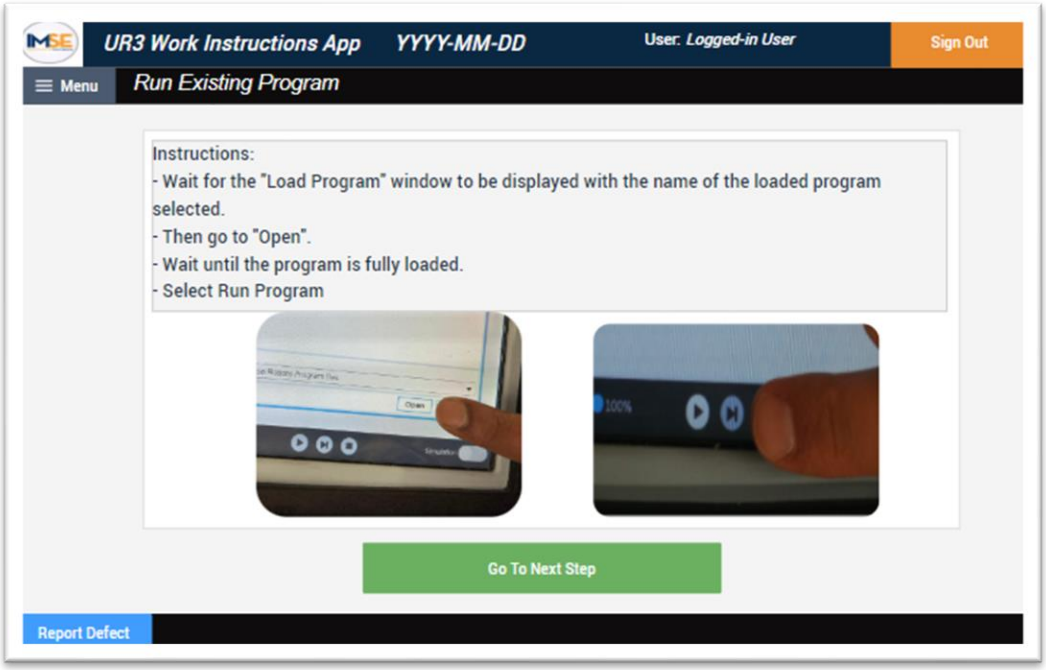

Figure 2-31 Step 12 Run Existing Program

The next step, called "Robot Location," is a simple step that combines trigger logic to ensure the operator is still on the path and everything is running smoothly. The design follows the same format as the other steps, and it just contains a statement to set the Robot in place and proceed with the next step. The operator just needs to confirm the green Button with the Go to Next Step, as it is shown in Figure 2-32.

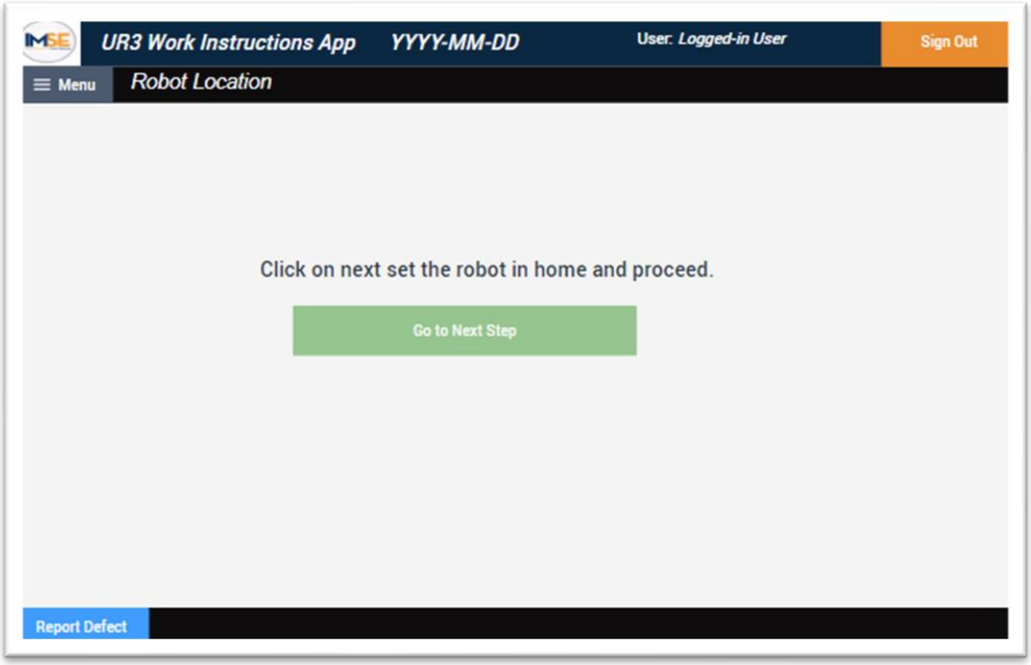

Figure 2-32 Step 13 Robot Location

Figure 2-33 shows the "Robot in Place" step window in which the operator will again follow the instructions provided in order to run the robot program. The instructions state that the illustration shown will be displayed once the program is fully loaded. Then they would be asked to select the play button located where the finger is showing. After the task is completed, the blinking Go to Step green Button needs to be selected in order to proceed with the next step.

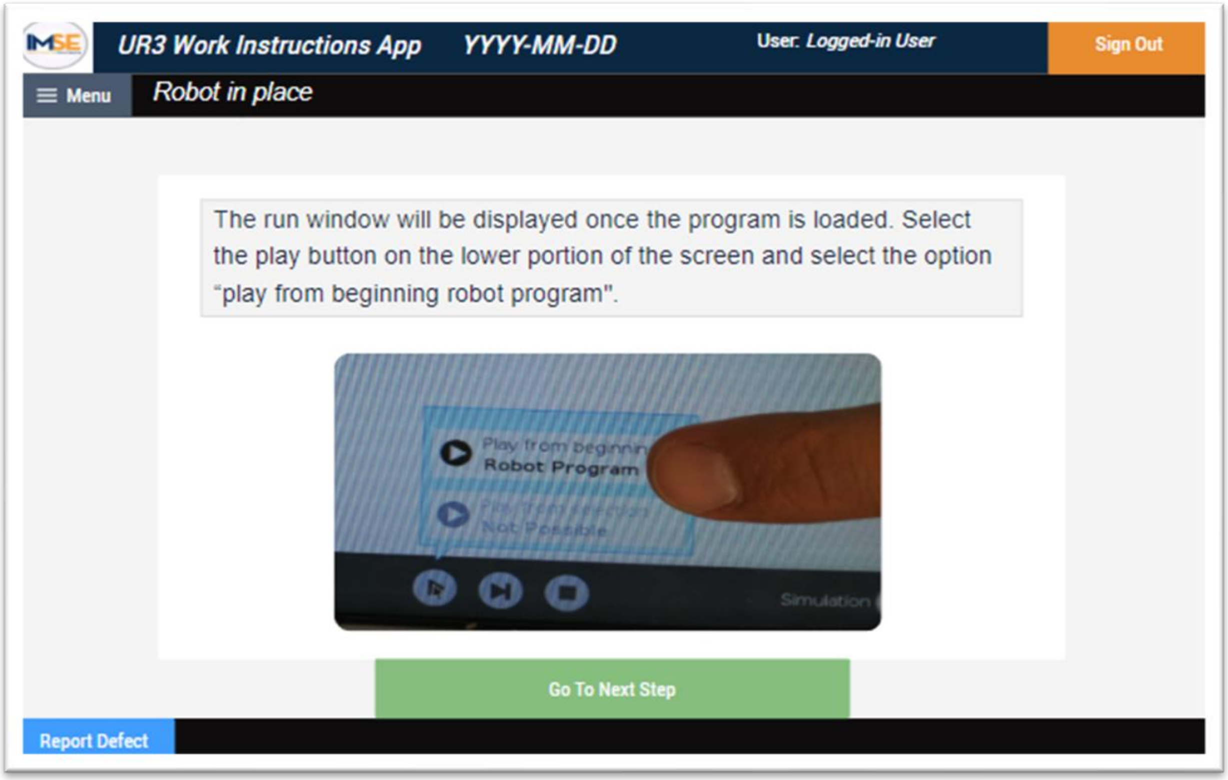

Figure 2-33 Step 14 Robot in place

Next, the "Robot not in place" step window shows two easy steps on how the operator will continue. The instructions and the illustrations indicate that the windows provided will appear in the teach pendant to accommodate the Collaborative Robot in its home position, as shown in Figure 2-34. Once the task is completed by the operator and the Robot is in its home position, then select the Go to Next Step button to continue with the next step.

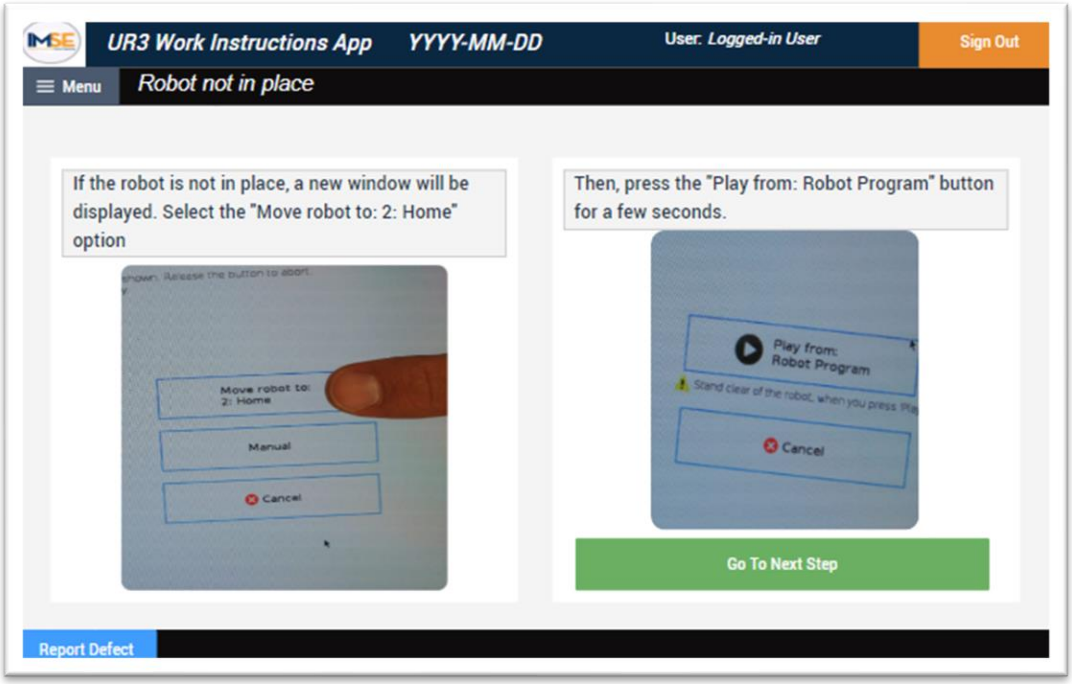

Figure 2-34 Step 15 Robot not in place

For the next step, called "Assembly complete," the operator is about to end the work instructions training. The instruction states that once the operation of the Robot is complete, the operator needs to stop the activity by selecting the stop button, as shown In Figure 2-35. Then the operator will follow the same format and select the Go to Next Step green button to move on with the next step to follow in order to almost complete the training.

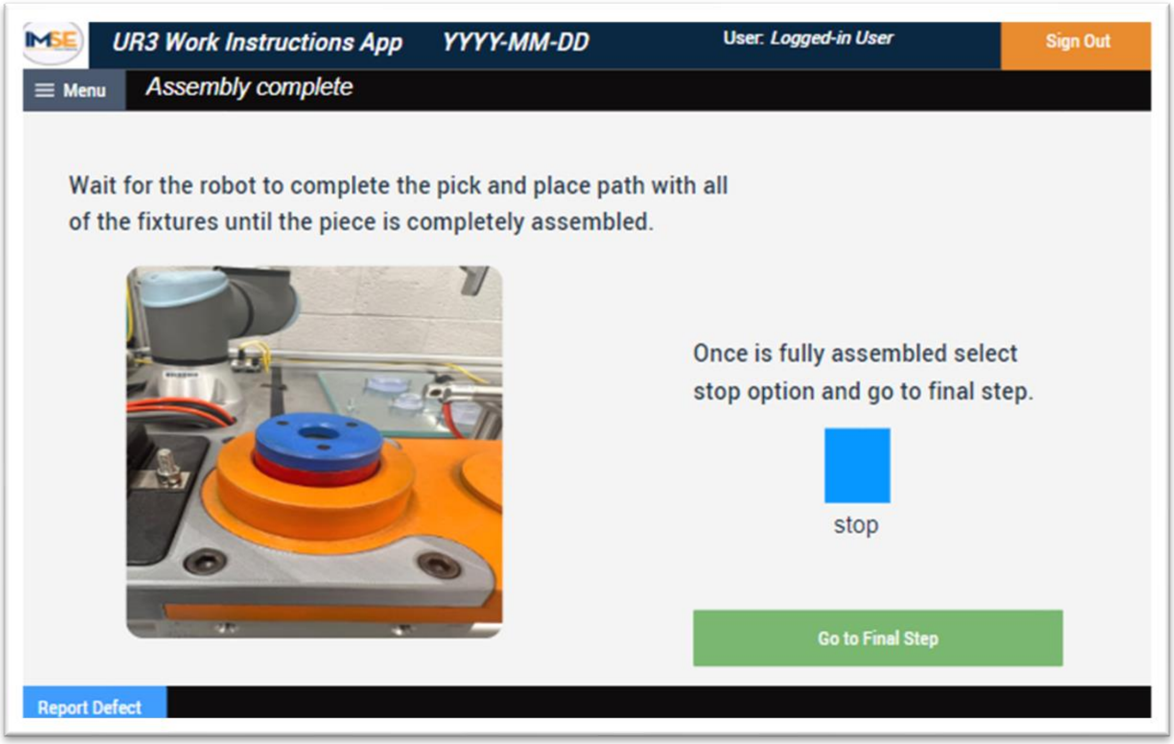

Figure 2-35 Step 16 Assembly complete

In the end, the operator will have a stepped window called "Final Step," like the one shown in Figure 2-36. This last step will record the participant attendance, and the information is stored in a table that will be shown on the results portion of this research. The operator just needs to select the Complete green Button to finish the training.

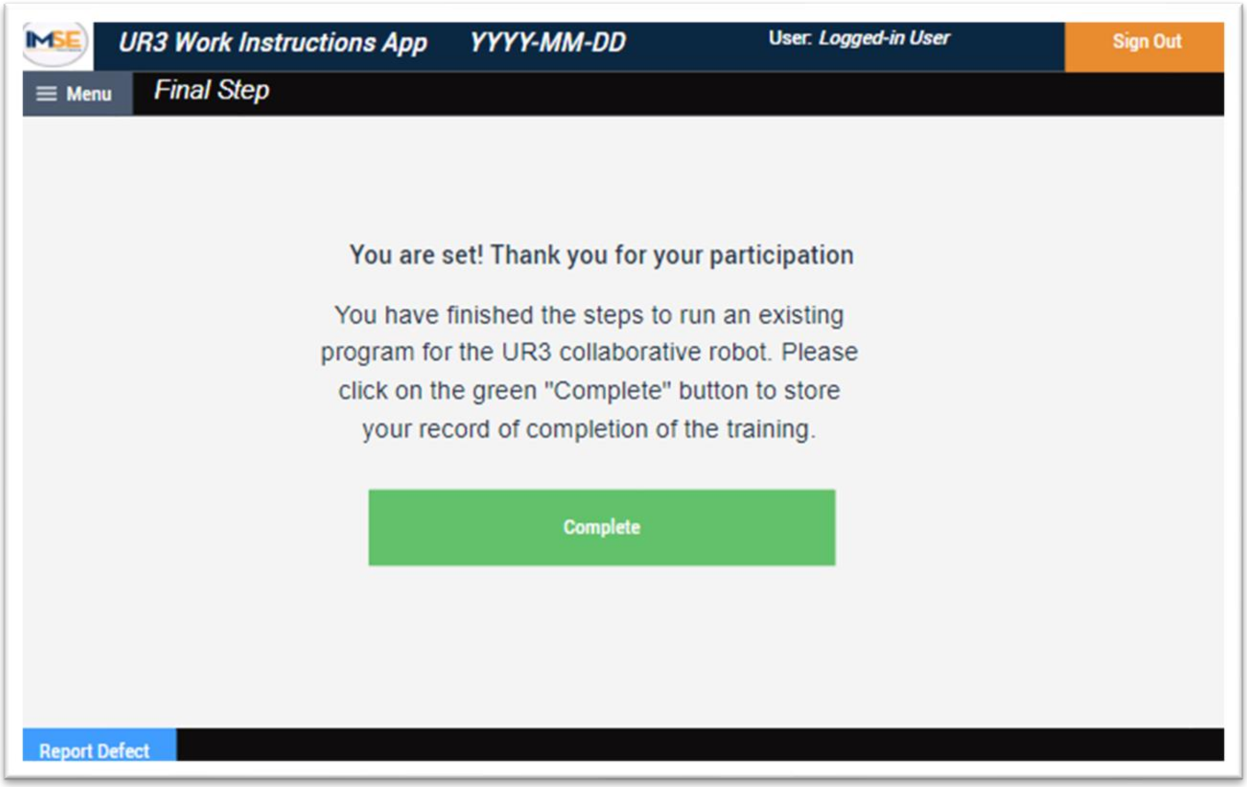

Figure 2-36 Step 17 Final Step

Figure 2-37 illustrates the step window containing the buttons that the user will encounter once he selects the report defect button. These buttons contain trigger logic that directs the user to either send a direct email with a pre-created message or submit a defect report form that can be stored once the data is inputted.

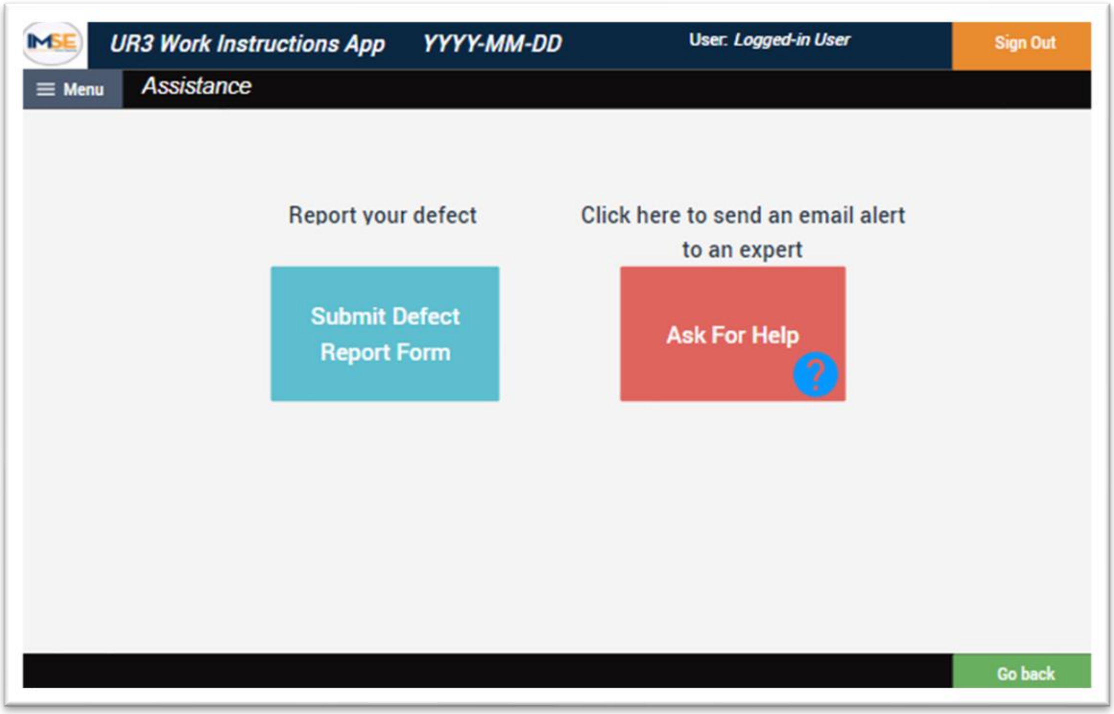

Figure 2-37 Assistance

Figure 2-38 Report Defect Form template will allow the user to submit a form whenever a defect is found. The data obtained from this report defect form will be stored in a table. This report defect contains four fields to fill; one is for typing the ID report generated. The user only needs to type 00 followed by the current date when the report is being generated. Next, a field where the user or the operator can describe the defect that is happening so that the data is stored and look at the common defects later to fix the error. Also, the report defect form contains a Boolean type of question asking if the fixtures were properly placed. This was one of the first steps in training, and if it was not performed, this could be the time to register it. Lastly, another Boolean type of question asks if the red Button on the robot station is released.

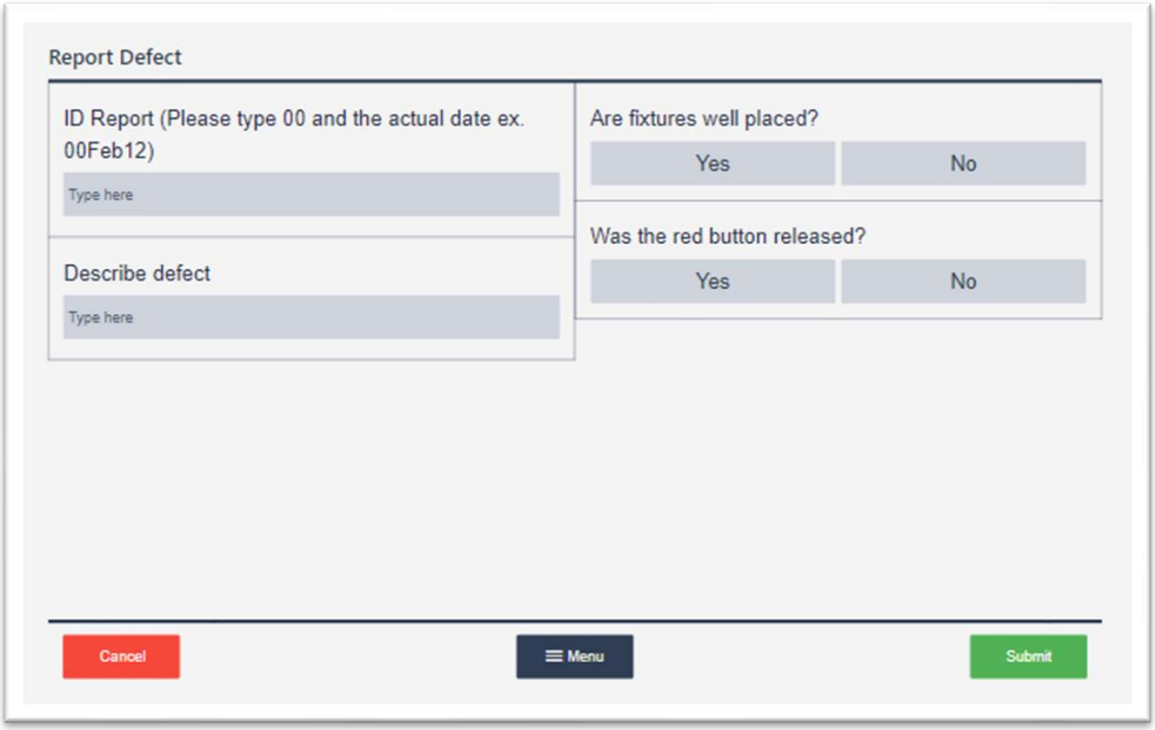

Figure 2-38 Report Defect

Chapter 3 -Results

After performing tests with different operators and making iterations to the application to see the different changes that were needed every time the app was running. The data is organized to present the results conducted in this research as well as the analytics created.

3.1 Iterations

After performing tests and determining which was the best version due to random tests created for the application, as shown in Figure 3-1, The published app was version 4, which contains the necessary instructions to follow for the operation of a pre-programmed program for the collaborative Robot. The rest of the published apps were useful for determining the specific instructions of the running, and by creating these iterations, the final version was used. Version 4 published shows the number of completions of the application as well as the average time the user takes to complete the application.

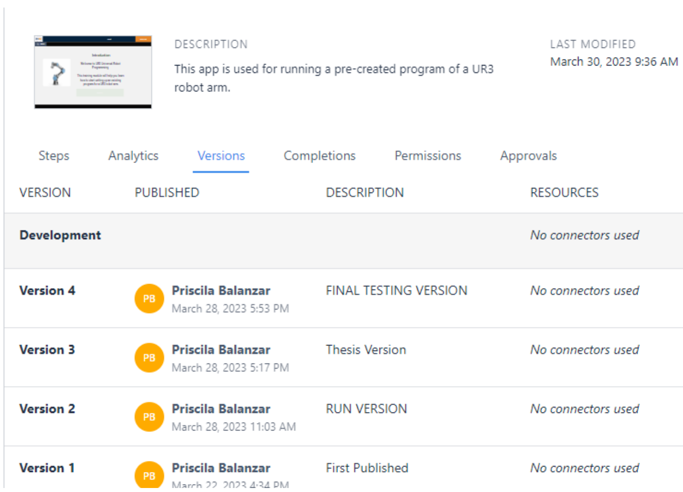

Figure 3-1 Iterations

3.2 Data collection

The report defects table shows the data filled by the operator when they were experiencing a defect. Based on the data collected from Figure 3-2 we can get aware of the difficulties from the operators while the operation of the robot. By having these type of forms we can have an analysis of or a list of difficulties either from the operation of the robot or for the running of the application. These in order to make the processes friendly for the operators and avoid errors in the process.

Report Defects

	ID	Report Defe...	Report Defe...	Report Defe...
1	80662181	Screen did not show turn ...	Yes	Yes
2	00Apr13	Emergency stop on penda...	Yes	No
3	0013	Robot position verification	Yes	Yes
4	001365	Robot position verification	Yes	Yes
5	001365257842	Robot position verification	Yes	Yes

Figure 3-2 Report Defect

Out of 7 operators utilizing the work instructions application, 5 presented an issue or a defect with the running of the Robot, which was faced by emailing the user with knowledge. The main issue was the Robot position verification.

3.4 Email Tool

As mentioned before, the application allows the operator to send an instant email to the person capable of fixing the situation. The operators made use of the send email tool 3 out of 7 completions that shows a message, as shown in Figure 3-8.

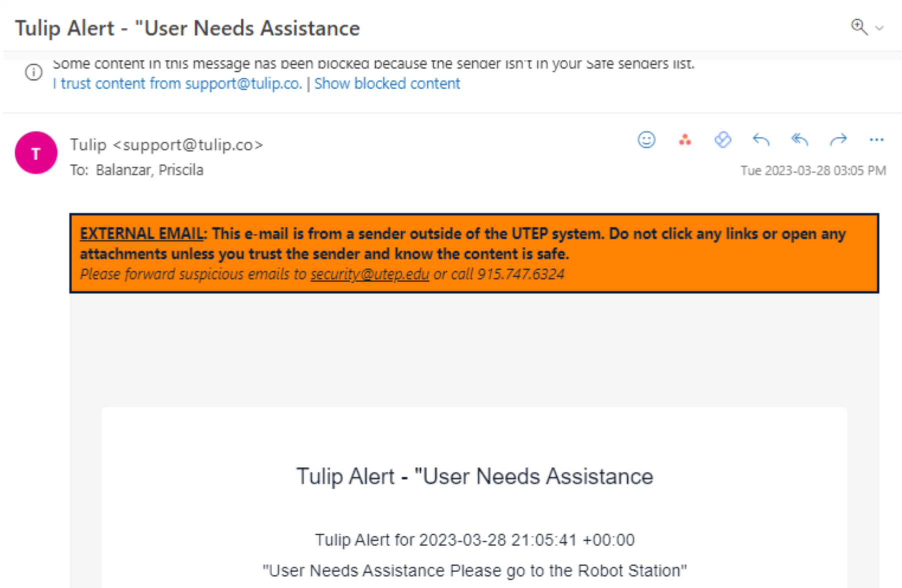

Figure 3-3 Email Tool

3.2 Count of completions

Tulip allows their users to create analytics based on different metrics; for this app, we used user completions in order to store the information and create the analytics. An app completion stores immutable data from a tulip application. When an is concluded, the app completions tab will contain the current values of all variables. This completion data is amenable to analytics analysis. After completion, users will be returned to the application's home interface by default. This behavior is always modifiable for the other transition categories.

Figure 3-4 illustrates the number of completions when the app was not completed, and Tulip allows the user to select the time frame accordingly to the analyses being analyzed.

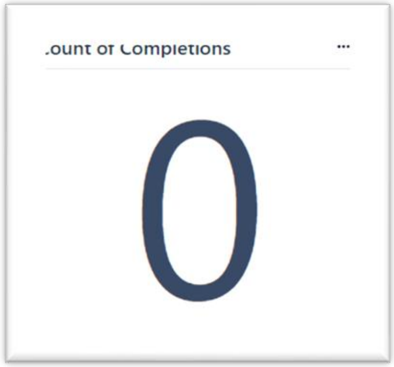

Figure 3-4 Count of completions 1

Now for Figure 3-5, the completion shows for a time frame of the current month testing the app. It shows seven completions same that were used to create the average times needed to run the application. This can be used to determine the number of completions for specific times in a manufacturing setting.

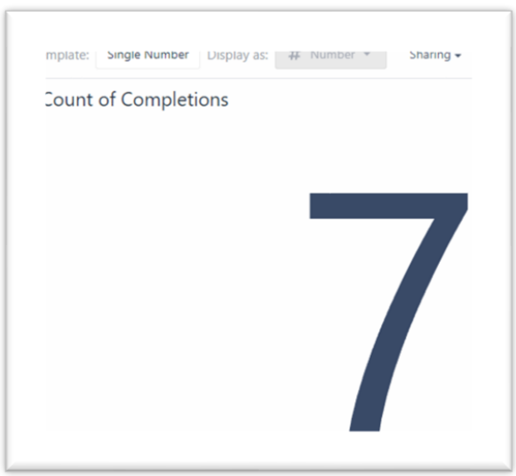

Figure 3-5 Count of completions 2

As mentioned before, Tulip allows the user to create different types of analytics. Figure 3-6 shows an average of The process Cycle Time that the operators took to run the application and complete the training of the Pre-programmed UR3 collaborative Robot program.

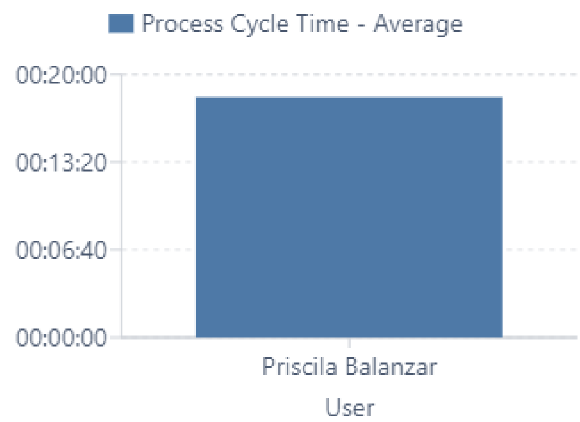

Figure 3-6 Average Time Completion

Also, in Figure 3-7, we can appreciate the number of completions along with the average process cycle time that the operators took to perform this activity.

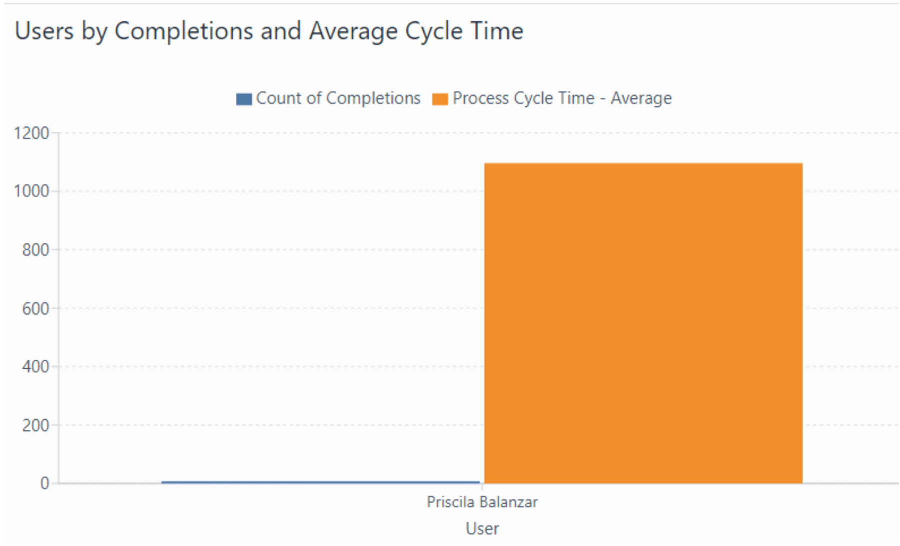

Figure 3-7 Count of completions with Avg Time

Table 3-1 shows the individual completion times of the seven operators running the application versus a Manual Learning standpoint of an engineer having the need to learn in a manual way how to perform the same activities that the application has. Eliminating the need for expert help will make a reduction of money in terms of salary.

Table 3-1 Completion Times Results

App Usage Completion Times	Manual Learning
Person 1- 19 Minutes	180 minutes
Person 2- 17.20 Minutes	
Person 3- 20 Minutes	
Person 4- 19.50 Minutes	
Person 5- 21.10 Minutes	
Person 6- 17.30 Minutes	
Person 7- 22.15 Minutes	

Figure 3-8 shows the comparison in minutes between the average time of 7 persons following detailed instructions of the application created on the Tulip software versus the time a person takes to learn the basic running of the collaborative Robot. The time on average, it takes to complete the application and learn the basic pre-programmed program is 19 minutes, versus a 180-minute comparison that a person takes to learn by their own method, either by asking other expertise mather of by looking at resources online to know how to operate the UR3 Collaborative Robot.

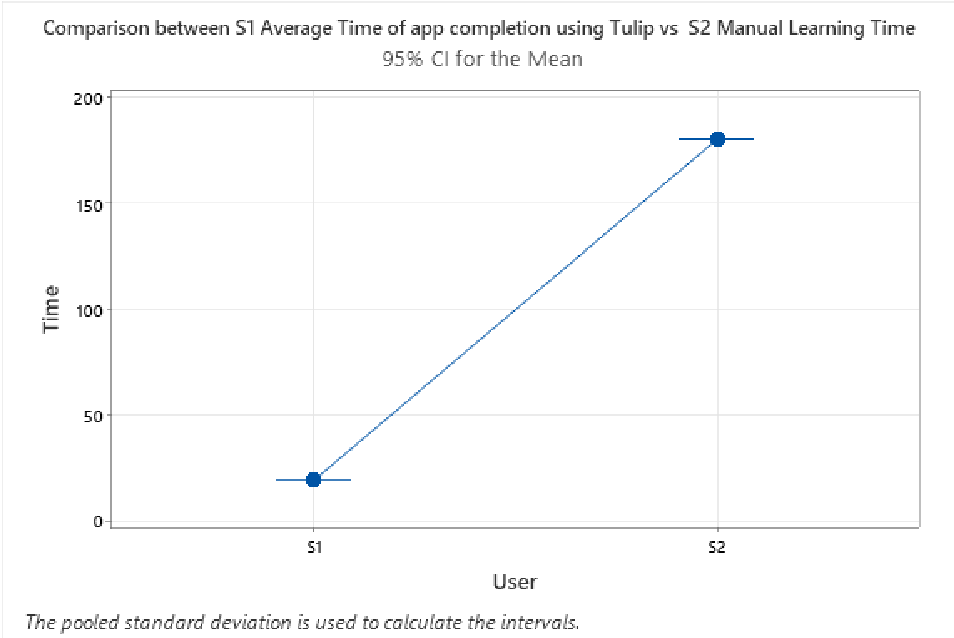

Figure 3-8 Comparison graph

Table 3-2 contains the App Usage Completion Times versus guided instruction times. We can see that having an expert or an engineer can reduce the time of learning how to run a pre-programmed collaborative robot program, but if we make an assumption of an engineer's salary of 30 dollars per hour and having to take all of his time being on the side of an operator to help in the running of the program. It can be cost-consuming in the long term because the engineer can perform other activities rather than helping an operator and losing time and considerable money.

Table 3-2 App vs Guided Instructions

App Usage Completion Times	**Guided Instructions Times**
Person 1- 19 Minutes	9.01 Minutes
Person 2- 17.20 Minutes	10 Minutes
Person 3- 20 Minutes	12.50 Minutes
Person 4- 19.50 Minutes	12 Minutes

Person 5- 21.10 Minutes	10.2 Minutes
Person 6- 17.30 Minutes	10 Minutes
Person 7- 22.15 Minutes	9.35 Minutes

Coming back to money, having an app can reduce the money spent on expertise by just taking the time to create the application needed for the specific task and giving a one-time training that can take up to 20 minutes, depending on the activity performed.

Chapter 4 - Conclusion and Discussion

The purpose of this research was to determine the feasibility of digitizing work instructions, in other words, to determine if creating manufacturing applications with software like Tulip would optimize the traditional manufacturing processes.

From the time standpoint, the user's average cycle time for using the work instructions applies to the collaborative Robot pick and place pre-programmed task. It did optimize the time that a person takes to learn how to operate the Robot versus a manual time because the average time for the first option is 19 minutes against the 3-hour standpoint of a manual learning a person with no knowledge takes to learn to do the same activity without the application.

On the second comparative, implementing a manufacturing instructions application versus having an expert next to the operation would not reduce the time because clearly having an engineering expert on the subject will be beneficial, but in the long term, it would cost a lot of money, implicating the reduction of activities that the engineer could have in another area.

Chapter 5 - Future Work

Based on the results and the conclusions of this work, there is an intended future work for this investigation is to create a more detailed work instructions application for future operators that allows the user to create programs for different tasks for the collaborative Robot. These detailed wotk instructions applications can include features that provide different scenarios that optimize the process for example embedding videos that guide the operators into a more clear instruction of the task to be performed. The research can be accompanied by surveys that made to the operators that ask for their different backgrounds, gender, age, and other metrics that can be analyzed to create comparative analysis for the results portion.

Another continuation is to get a connection with the machines, in this case, the collaborative Robot of the university. Following the previously mentioned future work, machine monitoring is an important concept to know. These because by connecting with the machines gathering the necessary data can be useful to provide solutions and optimize the processes.

5.1 Machine Monitoring

Machine monitoring plays another important role in this platform. According to Tulip, machine monitoring is a method for contextualizing machine performance. What is machine monitoring? According to Tulip, machine monitoring is a method for contextualizing machine performance within complex industrial processes in real time. Observing the machine operation under normal conditions allows you to have better tracking of improvement for your machines.

An example of machine monitoring before was a person standing next to the machine and counting when the cycle for the machine stops. These days, machine monitoring allows us to see when the machine is down for a changeover, maintenance, material shortage, safety incidents, lack of associates, and many others. You may have other objectives, such as uptime, downtime, and idle time. And it makes it easier to calculate Overall Equipment Effectiveness, better known as OEE. OEE is a metric or score that measures the productivity of a machine by comparing the performance of a machine to its relative capacity.

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Vita

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In August 2021, she enrolled in the Master of Science in Manufacturing Engineering to continue with her education at the University of Texas at El Paso and received it in May 2023. From 2021 to 2022, she worked as a TA for the Engineering Probability and Statistical Models. In 2022, she got an internship as an engineering intern to assist with new project implementation for Becton Dickinson in El Paso, Tx.

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