Warehouse Augmented Reality Program (WARP): A Web Tool for Warehouse Design and Operation Education

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Abstract

In this paper, we introduce the Warehouse Augmented Reality Program (WARP), its functionality, practicality, and potential use cases in education. We build this application on the backbone of WebXR. Using this application programming interface (API), we create an interactive web tool that displays a life-sized warehouse in augmented reality (AR) in front of users that can be viewed on a smartphone or a tablet. AR is a technology that displays virtual objects in the real world on a digital device's screen, allowing users to interact with virtual objects and locations while moving about a real-world environment. This tool can enhance warehousing education by making it immersive and more interactive. In addition, the tool can make warehousing operations more efficient and warehouse design less costly. We highlight how our tool can be applicable and beneficial to education and industry. We demonstrate how this tool can be integrated into a problem-based learning (PBL) assignment about warehouse layout design and order picking. The PBL activity involves comparing two different warehouse layouts (fishbone and traditional) by completing a set of order picking tasks in AR warehouse environments. The task is to perform single item picking over thirty orders and comparing the average order picking time per layout. Then, we use the results of these human subject experiments for validating the realism of the warehouse layouts generated by the tool by comparing the empirical completion times with the analytical results from the literature. We also administer a system usability scale (SUS) survey and collect feedback from industry experts.

Introduction

With the rise of warehouse demand, the industry adopts models to counteract e-commerce surges, reduce inventory, and enhance response time. Effective warehousing models can optimize inventory purchases, cut transportation expenses, and speed up delivery. In today's business landscape, warehouses are vital for modern supply chains and business success, but developing new layouts demands substantial capital, including construction costs (up to $950 per square meter), operational expenses, and safety systems [1]. Technologies such as augmented reality can offer solutions and support warehouse optimization [2].

Augmented reality (AR) is a technology that merges the physical and digital worlds. It has been proposed as a solution for managing manufacturing and logistics, such as efficient transportation [3]. In this paper, we present an augmented reality application called Warehouse Augmented Reality Program (WARP) with a user-friendly interface that aids users to understand different warehouse layouts with minimal cost and risk. This tool can not only be used in industry for testing different warehouse layouts, but also for training workers/students for different warehouse activities.

We conducted two studies to measure practical usage of WARP. The first study involved a short survey of users at Penn State Berks Campus during an industry-focused event. The second study involved a problem-based learning assignment activity which compares warehouse layouts through the use of WARP at Penn State Abington College.

Applications of Augmented Reality in Order Picking & Warehouse Layout Design

AR is a technology that displays virtual objects in the real world on a digital device's screen, allowing users to interact with virtual objects and locations while moving about a real-world environment. In contrast, a virtual reality user is immersed in a virtual world through a headset, allowing them to see and interact with a fully digital world controlled by the program.
In order picking, a person is tasked with retrieving a picklist of items from locations in a warehouse and bringing them back for retrieval. In a single-item picklist, the picker will grab one item, and then return to the starting location with it (see Figure 1 (left)). With a multiple-item picklist, the picker will visit multiple locations in a single trip, and then return once all items in the list have been picked (see Figure 1 (right)).

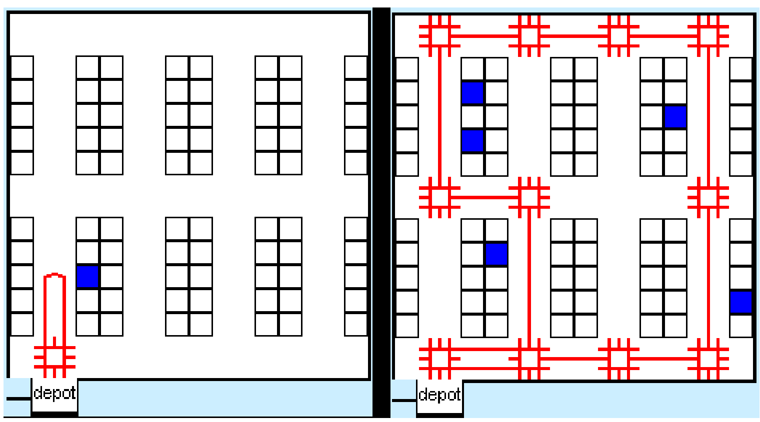
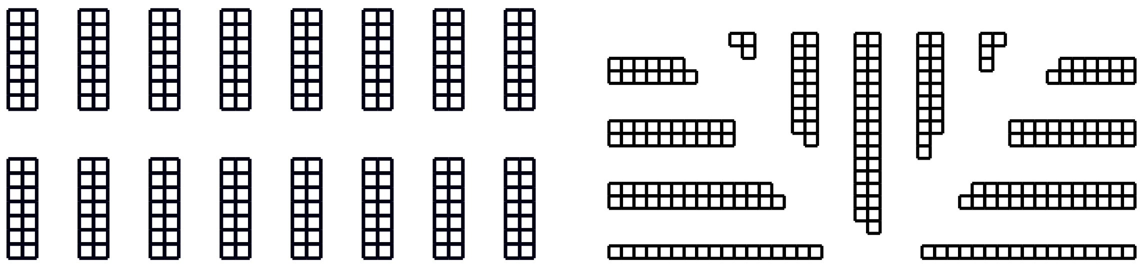


Figure 1: Single item pick (left) and multiple item pick (right). Blue squares indicate the location of the items to be picked.

Augmented reality in warehouse picking allows technology to aid in the picking process, using a digital interface to display information about the required items, their locations, and other items in the list. This can be further enhanced with headset devices, enabling the user to see information without a handheld device or turning their head away. Furthermore, optimal order routing and paths between items, which makes up the largest concern for picking efficiency, can be determined via computer simulations. Once the proper route has been calculated, this information can be displayed to the picker on an augmented reality device, via a map displaying the next location and the best path. An example AR application used in industry for order picking can be found in [4].
As for layout design, multiple warehouse layouts can be used for operations and should be considered for optimization. The most commonly used layout is the traditional layout. This design arranges racks in vertical rows with the entrance and deposit points in the middle. The rows may be dissected horizontally with one or more cross aisles. A traditional layout requires a

picker to move down aisles arranged in a grid, potentially resulting in a picker going farther out of their way to reach their goal than a straight-line path would allow, losing efficiency (see Figure 2a). As a result, a major research topic is aisle layout optimization to provide more efficient routing. An alternative is the fishbone layout which divides racks into three grouping zones with two diagonal aisles in a ”V” shape. This configuration allows for more direct routing for a greater area of the warehouse than the traditional layout (see Figure 2b).



(a) The layout of a traditional warehouse design.

(b) The layout of a fishbone warehouse design.

Figure 2: Two warehouse layouts used in this paper.

In [5], it has been shown that for a single-item picklist, the more direct access gives the fishbone layout an average travel distance of approximately 20% less than a traditional layout. However, the lack of a middle cross aisle means that subsequent picks must return to the starting location when traveling between the left and right sides of the warehouse. Subsequently, the efficiency bonus for the fishbone layout falls for each pick beyond the first, with traditional becoming more efficient at approximately five picks in one picklist [6].

Empirical research for warehouse operations focuses primarily on improving efficiency in existing traditional layout warehouses, and comparative analysis of fishbone and traditional layouts is primarily done using mathematical distance calculations without the human element, leaving AR layout comparisons mostly an untapped field. There have been several attempts to revolutionize warehouse operation optimization through augmented reality. In an experiment in [2], applications to aid in sorting items were created for Google Glass where an augmented reality box would be displayed and linked to the proper bin for the current item. In this study, users reported that using the hands-free interface was easier than using a traditional hand scanner, with noticeable improvements to both the increased speed at which sorting could be accomplished and a reduction of error rate from the application’s automatic bin checking.

In another study, AR has been introduced in a paper-making facility as a guidance system to find items [7]. This application could access the current stock and update it by scanning QR codes, then find the location of the given product and guide the user to the item. This guidance system was particularly useful in finding the desired product in an industry where the storage location of items frequently changes due to the production of perishables that must be used in a first-in, first-out order. Finally, warehouse centers in Greece were surveyed in [8] to gauge industry opinions on AR and gamification, the use of game-like elements in non-game applications. In this survey, 90% of the supervisors and 60% of the workers responded positively to the use of AR, with roughly half of the supervisors predicting a reduction in fatigue. Furthermore, roughly two-thirds of supervisors and pickers believed that introducing gamification would improve warehouse efficiency. For further literature on the use of AR in warehousing, see [9] and [10].

Warehouse Augmented Reality Program (WARP)

WebXR Device API(WebXR), is a new web standard developed by the Immersive Web Working Group from the W3C [11]; XR stands for cross reality, it is an all-encompassing term that includes augmented reality, virtual reality, and mixed reality. The goal of this API is to allow web pages to do the following:

- Check if the device has any XR capabilities.
- Get information about the XR device and its connected input devices.
- Render images on the XR device.

WebXR allows us to develop an AR application for visualizing and analyzing warehouse layouts in a practical environment on the web. WARP is built with the ThreeJS library, which handles the loading of 3D models and rendering of the scene in conjunction with WebXR [12]. With the capabilities from WebXR to perform a hit-test, project a ray from the camera to the ground, and determine the intersection point, it allows us to arrange virtual objects in the real world without extra preparations, such as printing a QR code onto paper like traditional AR applications. We also created a user interface to help the user navigate the warehouse environment as outlined in Figure 3.

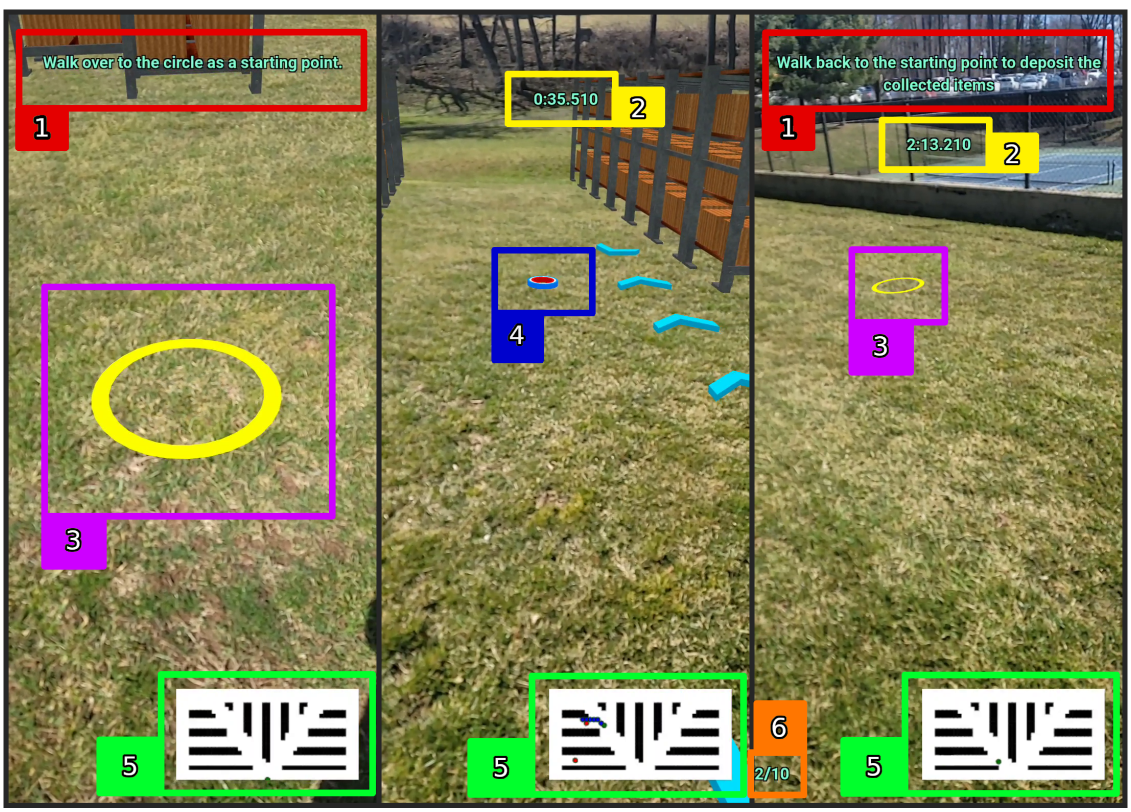


Figure 3: Image of WARP Running

The following explanations are numbered to represent the number in Figure 3:

1. The current direction given to the user.
2. The user's timer.
3. The circle denoting the pick and deposit point where order picking activity starts and ends.
4. The picking point.
5. The mini map, with green circle denoting the user's current location in the warehouse, the red circle is the picking point the user needs to go to, the blue circle is the guiding path from the user to the picking point, the guiding path also shows up as arrows in the AR environment.
6. The number of orders completed and the number of orders assigned to the user.

The picking point is a 3D object comprised of two sections: the outer and inner rings. The outer ring is colored red, while the inner ring is colored blue. The different colors create a contrasting color palette that will emphasize the picking point, even if the ground color is similar to one of the rings or if the user is color-blind. WARP follows multiple steps to deliver the desired warehouse experience to a user.
The flowchart in Figure 4 summarizes user interaction and the step-by-step program response, which can be summarized as follows:

1. When opening the web page, users are prompted to log in with their ID. Alternatively, users can sign in as a guest.
2. The user is redirected to the application page, and they can start their AR session.
3. If a user logs in with their ID, the application receives an ARD file (XML document) containing the layout of their assigned warehouse and picklists. If the user logs in as a guest, the application will load the default ARD file.
4. The application then conducts a hit-test and a 3D reticle will then appear, allowing the user to click the screen to construct the warehouse in augmented reality.
5. The user is prompted to go to the starting point.
6. Once there, the picking points will be displayed for the user. When the user reaches the picking point, it will automatically be picked.
7. After picking all points in the current list, the user returns to the starting point to deposit items, and then the next list appears. This process continues until all picklists are completed.
8. Once all picklists are finished, the user is prompted to either submit their result or redo to improve their time. If the user selects redo, all data is reset, and they return to the starting point. If the user selects to submit their results, and they are logged in with a valid ID, the data is sent to the database. Otherwise, the app will not send the data but act like it has.

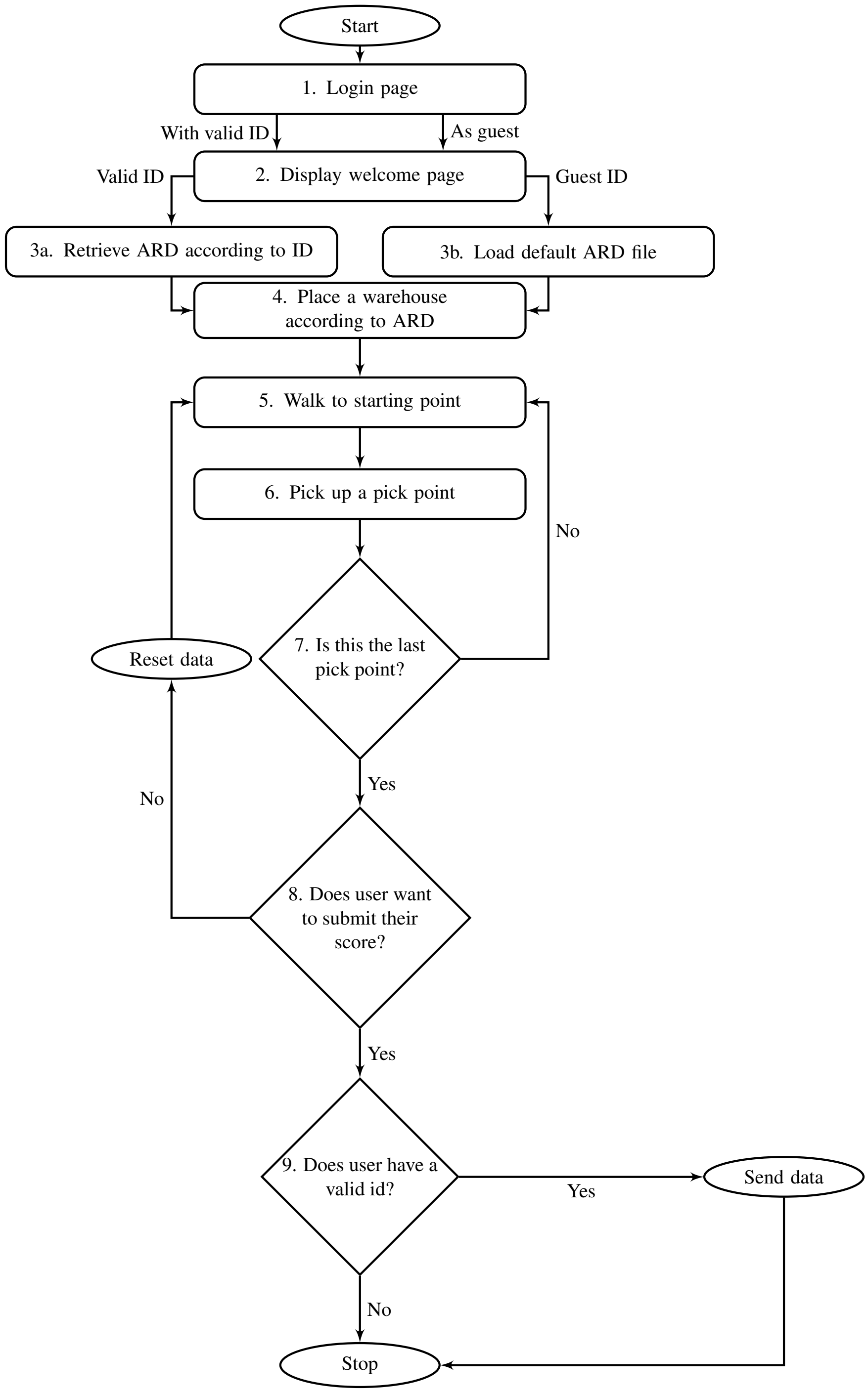


Figure 4: Single item picking operation with the WARP application

In the background, WARP tracks the user's location relative to the starting point and the current time. This allows us to collect data on the speed and how they navigate the warehouse. We built the database with MariaDB to store data collected from a user session [13]. A relational database allows us to easily organize, filter, and calculate the data necessary for research in the future.

Potential Use Cases of WARP

WARP has a multitude of applications in both academia and the warehouse industry. Sample academic use cases for teaching and research are as follows. Incorporating AR into a classroom can create a more interactive learning environment. Specifically, WARP will offer students a more hands-on way of learning the effects of warehouse design on picking operations by having the students see their ideas placed into the real world through a virtual lens and allowing them to see the effects of alternative layout designs first-hand from the perspective of an order picker. This type of technology could see the most use in industrial engineering and supply chain courses where the AR models could be used to learn about different warehouse layouts and the effects that changes to these designs could have on overall performance by placing the students in the shoes of a warehouse worker/picker. We show an example of this later in this paper where a group of students use WARP as part of a problem-based learning activity to compare the traditional and fishbone warehouse layouts in terms of order picking time.

WARP can assist with the understanding of various subjects such as ergonomics, facilities planning and design, and simulation. Under ergonomics, there are four subcategories: skeletal/muscular, sensory, environmental, and mental [14]. WARP would be able to display the sensory and environmental effects that a warehouse design may have on its workers, such as maneuverability and visibility. Effectively showing future industrial engineers why and how they may improve upon their designs in order to take the fundamentals of ergonomics into consideration. Furthermore, WARP would also be able to effectively help students understand the fundamentals of "facilities planning and design" by allowing them to track the time and efficiency of their designs. More so, WARP would be a useful tool for learning the fundamentals of warehouse simulation, as it simulates the warehouse design in an interactive web environment that can be viewed and explored from the first-person perspective.

Besides the above educational use cases, researchers can also use WARP for experimenting with and evaluating new ideas related to warehouse design and operation. From a research perspective, WARP is a cost-effective way to compare and contrast different warehouse models and operation policies, and to assess their realism and practicality for future use in the industry.

In addition to academic use cases, WARP can also be implemented in two main areas of the warehouse industry.

- **Warehouse design & development**: One can use the tool to view the impacts of different warehouse layouts on efficiency, space utilization, visibility, and other factors.

- **Order picking**: WARP can help guide order pickers to their next destination and act as a risk-free, cost-effective, and interactive training program. Implementing AR may create a more enriching and "fun" environment. AR in the workplace adds an element of gamification to work, which has been shown to increase productivity and morale [15].

Benefits of WARP

There are many benefits of of using WARP in an academic or industry environment. Some benefits of using WARP are:

- Reduction in error rate.
  - A guided path allows for the most efficient path to be taken.
  - Multiple indicators of correct picking location allow for increased clarity.
  - Provided instructions help if the picker loses focus or changes tasks.
- Increased accessibility.
  - Available on mobile devices.
  - Currently available on Android OS.
  - Planned to be available on iOS.
- Cost effectiveness.
  - No additional hardware expenses. Retail and warehouse industries may already have the hardware available.
  - Allows researchers to test different models without the expenditures of a physical infrastructure.
  - Consumes a low amount of mobile data (2.2 MB on startup and 54 KB per 30 minutes).

Limitations of WARP

Since WebXR is a relatively new technology, only being available since 2019 with the release of Chrome 79 [16], it still has yet to be widely adopted. Most of its applications currently focus on VR, and because of that, only a limited number of libraries and development tools are available for AR. Other limitations include:

- Apple's iOS does not have official support in their native browser, Safari.
- The application also does not support a stereoscopic mode (i.e., displaying two slightly different images for each eye, creating a 3D effect.) for use in a cardboard XR headset since the phone only accesses one camera at a time.
- The absence of stereoscopic mode also prevents users from using the application hands-free, requiring the user to observe the AR warehouse on their phone's screen.
- Currently, the app does not support VR controllers or use of another phone as input devices to interact with the AR world.

Experiments, Sample Learning Activity, and Results

Usability Study

We conducted a system usability scale survey on twelve test users during an industry-focused event at the Penn State Berks campus. The System Usability Scale (SUS) was used which offers a swift and dependable method for assessing usability [17]. The survey comprises a 10-item questionnaire with five response choices, ranging from "Strongly Agree" to "Strongly Disagree." This survey enables the evaluation of diverse products and services, such as hardware, software, mobile devices, websites, and applications. The feedback received was predominantly positive. Table 1 outlines the statements proposed and average scores, where each survey item is scored on a scale from one to five. The overall SUS score was 68.8 which translates to an overall rating of above average.

Table 1: SUS survey results

Proposed Statement	AVG Score
I think I would like to use this AR Warehouse tool frequently.	3.08
I found the AR Warehouse tool unnecessarily complex.	2
I thought this AR Warehouse tool was easy to use.	4.17
I think that I would need the support of a technical person to be able to use the tool.	2.58
I found the various functions in this tool were well integrated.	3.67
I thought there was too much inconsistency in the AR Warehouse tool.	2.17
I would imagine that most people would learn to use this tool very quickly.	4
I found the AR Warehouse tool very cumbersome to use.	2
I felt very confident using the AR Warehouse tool.	3.67
I needed to learn a lot of things before I could get going with the AR Warehouse tool.	2.33

A Sample Problem-Based Learning Activity Using WARP

We conducted a group learning activity with a small number of volunteer students from Penn State Abington College. All student volunteers are sophomore students majoring in computer science. In this group learning activity, which presents an example of how PBL can be integrated with immersive technologies [18, 19], students first learn about the fishbone layout and that it is expected to achieve an average of 20% less travel distance/time over the traditional layout in single-item picking operations based on the analytical results reported in a research paper in [5]. Then, students were tasked to validate the analytical findings empirically using the WARP tool. In the first stage of the activity, each student completed the following tasks:

1. Perform an order picking operation using WARP (collect single item from a random location in a given warehouse, see Figure 5).
2. Record order picking time.
3. Perform above two activities 30 times (this means each student needs to finish 30 orders where each order has a single item to collect, total 60 picks per student).

4. Calculate average order picking time per order.

5. Perform above activities for both traditional layout design and fishbone design.

Figure 5: A student volunteer picking items in a virtual fishbone layout

Once each student finished their individual activity using WARP, they then worked as a group to complete the following tasks:

1. Calculate average order picking time across all orders and all order pickers (mean of 6 students' order picking time average) for the traditional and fishbone layout designs.

2. Compare the average of these two designs.

3. Based on the statistical analysis and augmented reality experience they received, draw conclusions about the performance, benefits, and pitfalls of the two layout designs.

In their analysis, students concluded that in a picklist consisting of single-item picks, the fishbone layout performs 9% better in terms of the order picking time, which is lower than the expected 20% based on analytical findings in the literature. Students investigated that the difference might be also related to the size of the virtual warehouses they did the experiments since the fishbone layout performs better in larger size warehouses than smaller size warehouses. Table 2 summarizes the results from the activity. It is important to emphasize that the sample size in this preliminary experiment is too small to draw statistically reliable conclusions, but rather the purpose of this example is to show the potential of WARP as a teaching and learning tool.

Table 2: Average Order Picking Time (sec) per picker for Traditional and Fishbone layouts

Order Picker ID	Traditional	Fisbhone
1	39.27	38.95
2	36.49	33.29
3	40.76	38.21
4	48.40	36.73
5	51.94	50.90
6	43.58	38.74
Overall Average	43.41	39.47

Comparing the total averages of both layouts, a difference of 9.08% was found as seen in Equation 1 below. Please refer to Table 3 for variable definitions.

Table 3: Average Time Per Layout

Layout	Variable	Average Time (seconds)
Traditional	t_1	43.41
Fishbone	t_2	39.47

$$\frac{t_1 - t_2}{t_2} = \frac{43.41 - 39.47}{43.41} = 0.0908 = 9.08\% \tag{1}$$

Conclusions

This paper presented an overview of the Warehouse Augmented Reality Program (WARP) and investigated its usability and potential educational applications as a teaching and learning tool related to order picking and layout design in warehouse operations. We performed a usability study using the System Usability Scale questionnaire and the results indicated an acceptable usability level for the tool. We also performed a preliminary experiment with a small group of students to show the use of WARP as part of a group problem-based learning activity. For future development, we plan to provide more accessibility to WARP by implementing compatibility with iOS devices, support for VR controllers, and other warehouse experiences such as product identification and item sorting assistance. We also plan to integrate this tool with augmented reality problem-based learning assignments where students will solve warehouse related problems using augmented reality.

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