Zamorano University

Food Science and Technology Department

B.S. in Food Science and Technology

Special Graduation Project

Evaluating the Effectiveness of a Virtual Reality Aquaponic Greenhouse Tour as an Educational Tool for Enhancing Food Safety Knowledge

Student

Stephany Margarita Cándido Monterroza

Advisors

Jorge Cardona, Ph.D.

Yaohua Feng, Ph.D.

Honduras, November 2025

Authorities

KEITH L. ANDREWS

Rector i.a.

ANA M. MAIER ACOSTA

Vice-president and Academic Dean

ADELA M. ACOSTA MARCHETTI

Head of Food Science and Technology Department

JULIO NAVARRO

General Secretary

Contents

Table Index

Figure Index

Abstract

Food safety (FS) is a global public health concern that requires innovative approaches to improve knowledge and practice. Virtual Reality (VR) has emerged as a promising tool for immersive and effective training. The objective of this study was to evaluate the effectiveness of a VR Aquaponic Greenhouse Tour for enhancing knowledge of (FS) and aquaponics. This project was conducted in two phases: at Purdue University (I), and Zamorano University (II) using VR headsets and laptop-based tours. Descriptive and explanatory statistics were applied to evaluate quiz performance and survey responses. A Mann-Whitney U test compared quiz performance by gender (I), and a t-test assessed differences before and after the tour (II), both at a 95% confidence level ($p \leq 0.05$). Descriptive analysis summarized demographic data and participants' perceptions through Likert-scale responses. Findings revealed that the VR tour significantly improved participants' knowledge, with quiz scores showing a statistically significant increase after the tour in all groups regardless of gender and majors. The study also found that the tour increased participants' interest in both FS and aquaponics. Most participants considered VR experience an effective learning tool and a viable alternative to in-person farm tours. The study concluded that VR-based tours were an effective way to teach FS and aquaponics in a format that is practical and accessible, allowing more people to benefit from this training without being limited by distance or physical constraints. These insights contribute to understanding innovative educational technologies and provide recommendations for educators and stakeholders in food and agricultural systems.

Keywords: Digital simulation, educational technology, immersive environment, safe food handling, sustainable farming system

Resumen

La inocuidad es un problema de salud pública global que requiere enfoques innovadores. La realidad virtual (RV) emerge como una herramienta prometedora para ofrecer capacitaciones inmersivas y efectivas. Este estudio buscó evaluar la efectividad de un tour de RV en un invernadero acuapónico para mejorar el conocimiento sobre inocuidad y acuaponía. El proyecto se desarrolló en dos fases, en la Universidad de Purdue (I) y en la Universidad Zamorano (II), utilizando visores de RV y tours basados en computadora. Se aplicaron estadísticas descriptivas y explicativas. Se usó la prueba U de Mann-Whitney (I) y una prueba t (II) para comparar el desempeño en cuestionarios antes y después del tour, con un nivel de confianza del 95% ($p \leq 0.05$). El análisis descriptivo resumió datos demográficos y percepciones de los participantes. Los resultados mostraron que el tour de RV mejoró significativamente el conocimiento de los participantes, con un aumento estadísticamente significativo en las puntuaciones de los cuestionarios, sin importar el género o la carrera. El tour también incrementó el interés de los participantes en inocuidad alimentaria y acuaponía. La mayoría consideró la experiencia en RV una herramienta de aprendizaje efectiva y una alternativa viable a las visitas presenciales a granjas. El estudio concluyó que los tours basados en RV son una forma eficaz de enseñar sobre inocuidad y acuaponía en un formato práctico y accesible, permitiendo que más personas se beneficien de esta capacitación sin limitaciones de distancia o condiciones. Estos hallazgos contribuyen a la comprensión de las tecnologías educativas innovadoras.

Palabras claves: entorno inmersivo, manipulación segura de alimentos, simulación digital, sistema de cultivo sostenible, tecnología educativa.

Introduction

Food safety is a global public health issue, with recurring incidents of foodborne diseases. Food safety training currently focuses on the theory that an increase in knowledge about proper food safety protocols will reflect on improved behavior (McFarland et al., 2019). Traditional food safety training programs are primarily designed to impart knowledge through in-person sessions, often relying on presentations.

Virtual Reality (VR) simulates a virtual environment that immerses users to the extent that they have the feeling of "being there" (Bowman & McMahan, 2007). VR technology presents an important opportunity to improve the effectiveness of safety and safety-relevant training due to its increased level of presence, ability to fail safely, and capability in presenting several scenarios that are difficult to replicate in the real world due to financial constraints or safety concerns (Stefan et al., 2023). Virtual education offers several advantages, including lower costs, consistent content delivery, expanded reach, and greater flexibility (Almahasees et al., 2021).

Virtual training materials can be accessed by a broad audience in multiple locations simultaneously, allowing participants to complete training at their convenience. VR's immersive environments captivate students' attention more effectively than traditional educational tools, making it particularly beneficial for those with learning disabilities that hinder their engagement with conventional teaching methods. Customization and accessibility are also major advantages of VR; it allows for tailored educational experiences that meet individual learner needs, thereby supporting the principles of inclusive education (Dahiya, 2024). Additionally, virtual training supports both synchronous and asynchronous learning, accommodating diverse schedules. Despite these benefits, virtual training often lacks hands-on activities and interactive components, which have been shown to enhance engagement and retention in-person training (Insfran-Rivarola et al., 2020).

Addressing this limitation is critical to ensuring the effectiveness of virtual food safety education. By leveraging VR technology, participants can engage with farm environments in an

interactive manner, receiving general and food safety information through an immersive farm tour experience. A study by Schütz et al. (2022) highlighted the growing interest in VR farm tours but did not incorporate a training component. By integrating interactive elements comparable to those found in guided farm tours, VR training can enhance knowledge retention by stimulating multiple senses, including sight and sound (Pribadi et al., 2024).

This technology also enables training across various farm types, such as aquaponics. Aquaponics is an indoor-capable alternative agricultural method that combines aquaculture, the production of fish (and non-fish aquatic animal species), and hydroponics, cultivation of plants in water instead of soil (Spradlin & Saha, 2022). In recent years, increasing public resources have been invested in promoting commercial aquaponics as the quest for sustainable aquaculture practices expand. Aquaponics is considered “an emerging technological innovation system”, it is more complex than many other farming methods.

The aquaponics system, which integrates multiple components, can be difficult for many people to understand. Moreover, there is often a large gap between the existing experience and training of the novice grower and the complex set of skills required to successfully run aquaponic systems (Greenfeld et al., 2019). These systems are also complex and not always easy to visit or study in person. However, through virtual reality tour, stakeholders can explore an aquaponic system, understand how it works, and learn how to keep food safe by identifying risks and proper hygiene practices.

This type of training helps people learn by seeing and doing, even if they are far from a real farm. Implementing VR food safety training has the potential to transform how people learn and acquire crucial knowledge, making learning more engaging, accessible, and effective. Moreover, it can be used in schools, training centers, or even at home, giving more people the opportunity to understand food safety practices.

The main objective of this study was to evaluate the effectiveness of virtual reality as a tool for improving food safety education, with the aim of providing valuable information on how immersive technologies can enhance learning experiences. In addition, the study aimed to assess how virtual tours increased participants' knowledge and understanding of aquaponic systems as an alternative to traditional in-person farm visits. By examining these aspects, the research contributes to academic and practical knowledge about innovative educational methods, promoting more engaging, accessible, and effective food safety training through virtual reality.

Materials and Methods

Location

The first phase of the study was conducted in Philip E. Nelson Hall of Food Science at Purdue University, is located at 745 Agriculture Mall Drive, West Lafayette, IN 47907. The data was collected during an event called Spring Fest. Spring Fest is an annual festival at Purdue, where participants can engage in interactive activities covering a range of subjects, from the College of Agriculture. The second phase of the study was conducted in the at Zamorano University¸ located in Honduras.

Materials

Materials used in this study included the MetaQuest 3 virtual reality headset, which participants used during the first part of the study to experience the virtual tour of the aquaponic greenhouse. In the second part, participants accessed the laptop version of the tour using computers. For comfort and safety, chairs were provided so participants could remain seated during data collection. The content of the virtual tour was recorded at a pilot-scale aquaponic system that is part of the When Blue is Green (BiG) project conducted by Purdue students. This system is located within the Department of Horticulture at Purdue University.

Participants Recruitment

A recruitment flyer was distributed via email and social media to recruit participants. To be eligible to participate in this study, participants had to be 18 years or older, proficient in English, and comfortable using virtual reality technology, such as a laptop or a VR headset (Meta Quest 3). Interested participants completed a registration survey via Qualtrics and Microsoft Forms to provide their contact information. Eligible study participants were contacted via email to confirm their participation. All participants in the first part of the study received an incentive as compensation for their time.

First Phase of the Study (Purdue University)

Institutional Review Board (IRB)

Before data collection began, the Institutional Review Board at Purdue University (IRB-2024-1241) approved the research protocol. The study consisted of two parts: tour experience and a survey.

Study Procedure

Participants were first introduced to the study's goals and asked to carefully read and sign the *Research Participant Consent Form*. Then, those using the Virtual Reality headsets received instructions on how to wear the device comfortably and navigate the virtual tour. The virtual aquaponic greenhouse tour covered approximately 15 to 20 minutes, during which participants independently explored four different environments (system, plant, fish, and food safety) while seated for safety and comfort. Each environment contained multiple informational sections, and after viewing all the content, a short quiz of 3 to 4 questions appeared to assess participants' understanding of the material.

Second Phase of the Study (Zamorano University)

Study Procedure

Participants were introduced to the study's goals and asked to carefully read and sign the *Research Participant Consent Form*. Those who completed the laptop version received instructions on how to navigate the virtual tour. Before starting the tour, these participants took a short pre-tour quiz consisting of 10 questions covering the four environments of the tour: system, plant, fish, and food safety. The virtual tour experience lasted between 15 and 20 minutes, during which participants independently explored the stationary tour while seated for safety and comfort. The aquaponic greenhouse tour was divided into the same four environments, each containing multiple pieces of information. During the tour, participants were given a printed quiz with the same 10 questions from the pre-tour assessment, with 2 or 3 questions related to each section, to evaluate their understanding of the material presented.

Survey

Following the tour experience, an online survey via Qualtrics XM was presented to participants to evaluate the user experience, explore the potential of the VR tour as an educational tool, and gather their demographic information. A QR code was provided to participants to access the survey, or a computer was offered if they could not or did not want to use their personal device.

Experimental Design and Statistical Analysis

Descriptive and explanatory statistical analysis was used to evaluate quiz performance and survey responses from participants of the Virtual Reality Aquaponic Greenhouse Tour. Descriptive statistics summarized demographic data and quiz results. In the first phase of the study a Mann-Whitney U test was conducted to compare quiz performance between male and female participants and in the second phase of the study a t-test were conducted to compare performance between before the virtual reality tour and after the virtual reality tour, using a 95% confidence level ($p \leq 0.05$) in both. Descriptive analysis was used to better understand how participants felt about the virtual tour experience in the two phases. Their answers to the Likert-scale survey were summarized using frequencies in both phases.

Results and Discussion

First Phase

Demographic Characteristics

A total of 26 participants completed the Virtual Reality Aquaponic Greenhouse Tour, including 17 males and 9 females (Table 1). The highest level of education among participants varied, with 35% holding a high school diploma, 30% a bachelor's degree, and 35% a post-bachelor's degree. Before the virtual experience, most participants (73%) had visited a general farm in person.

Table 1

Demographic characteristics of the Virtual Reality Aquaponic Greenhouse Tour.

Characteristics	Total n (%) (n =26)
Gender	
Male	17 (65)
Female	9 (35)
Age	
18-24	15 (58)
25-34	12 (42)
Ethnicity	
Hispanic or Latino, Latinx or Spanish	14 (54)
White	8 (31)
Asian	4 (15)
High level of education	
High school	9 (35)
Bachelor's degree	8 (30)
Post bachelor's degree	9 (35)
Visited a farm in person before	
Yes	19 (73)
No	7 (27)
Experience in aquaponics	
Yes	1 (4)
No	25 (96)

Quiz Tour Results

The quiz results showed (Table 2) that participants had high comprehension of the content presented during the virtual tour. Correct answers ranged from 81% to 100%, with perfect performance in questions related to the system environment and food safety. Slightly lower performance in the "plant" and "fish" sections may suggested that these topics were more challenging or less familiar.

Table 2

Results of correct and incorrect answers on the tour quiz.

Section	Total correct answer, n (%) (n =26)	Total incorrect answer, n (%) (n =26)
System		
Question 1	25 (96)	1 (3)
Question 2	26 (100)	-
Plant		
Question 1	22 (85)	4 (15)
Question 2	26 (100)	-
Question 3	21 (81)	5 (19)
Fish		
Question 1	25 (96)	1 (3)
Question 2	24 (92)	2 (8)
Question 3	21 (81)	5 (19)
Food safety		
Question 1	25 (96)	1 (3)
Question 2	24 (92)	2 (8)

Quiz scores were similar between male and female participants in all sections (Table 3). The Mann-Whitney U test analysis confirmed that there were not statistically significant differences between genders ($p > 0.05$) in any of the environments (Table 4). These results may have been influenced by the small sample size, which might not have been large enough to detect a significant difference.

Table 3

Correct and incorrect answers by gender.

	Female		Male	
Environment	Total correct answer, n (%) (n =9)	Total incorrect answer, n (%) (n =9)	Total correct answer, n (%) (n =17)	Total incorrect answer, n (%) (n =17)
System	9 (100)	-	16 (94.1)	1 (5.9)
Plant	5 (55.6)	4 (44.4)	11 (64.7)	6 (35.3)
Fish	7 (77.8)	2 (22.2)	11 (64.7)	6 (35.3)
Food safety	8 (88.9)	1 (11.1)	15 (88.2)	2 (11.8)

Table 4

Mann-Whitney U test analysis of correct responses by gender.

Environment	Female (n=9) Correct answers (Mean ± SD)	Male (n=17) Correct answers (Mean ± SD)	Total (n=26) Correct answers (Mean ± SD)	p Value
System (2)	2 ± 0	1.94 ± 0.24	1.96 ± 0.19	0.518
Plant (3)	2.56 ± 0.53	2.65 ± 0.49	2.61 ± 0.49	0.678
Fish (3)	2.78 ± 0.44	2.59 ± 0.62	2.65 ± 0.56	0.483
Food safety (2)	1.88 ± 0.33	1.88 ± 0.33	1.88 ± 0.32	1.0

Survey Results

A total of 47 questions were completed in the survey. The document analyzed participants' responses regarding the effectiveness of the virtual farm tour as an educational tool for promoting knowledge of food safety and aquaponics.

Aquaponics Knowledge.

Before participating in the tour, most respondents had limited knowledge of aquaponics, with only 19.3% reporting high familiarity (Figure 1). After the tour, 96.2% (Figure 2) indicated their knowledge had improved significantly. The results indicated that the tour helped participants with little previous knowledge to better understand aquaponics, supporting its potential as a useful educational tool. Chang (2022) developed a web-based virtual farm application to study its effects on education. Users played the role of a farmer raising crops and poultry, observing the farm's growth as they interacted with the application. The farm was designed to simulate real situations encountered by a farmer to enhance users' interest and motivation to learn agricultural knowledge and experience farm life. They found that the virtual farm significantly enhanced students' learning effectiveness and motivation.

Figure 1

How familiar were you with aquaponics before the virtual reality tour?

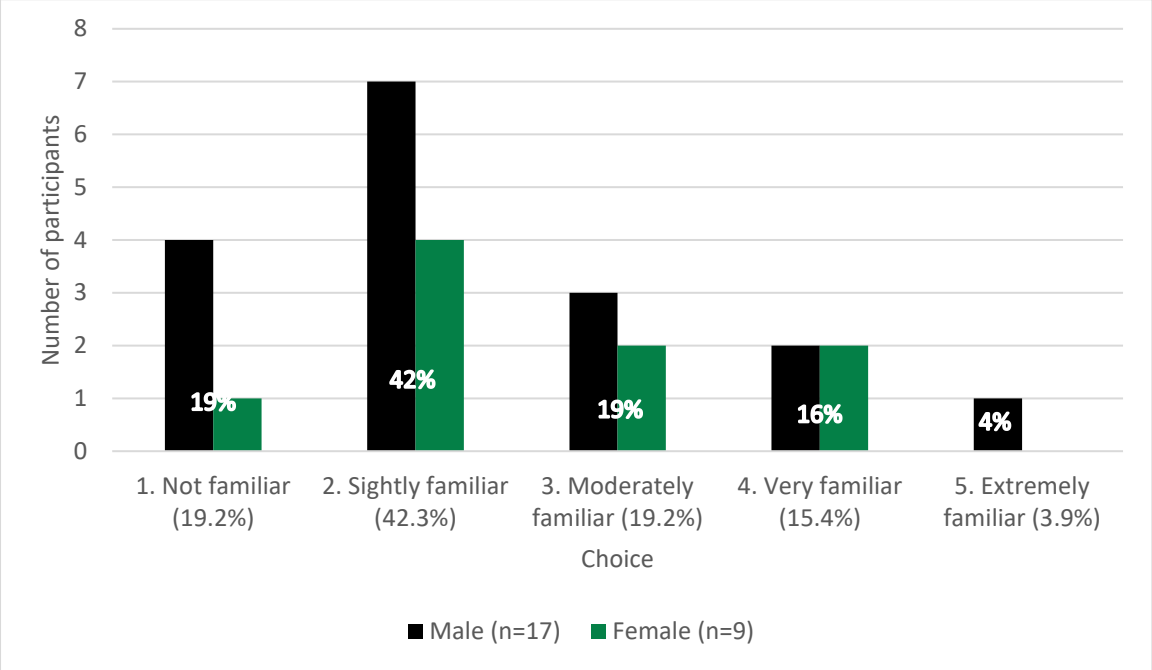
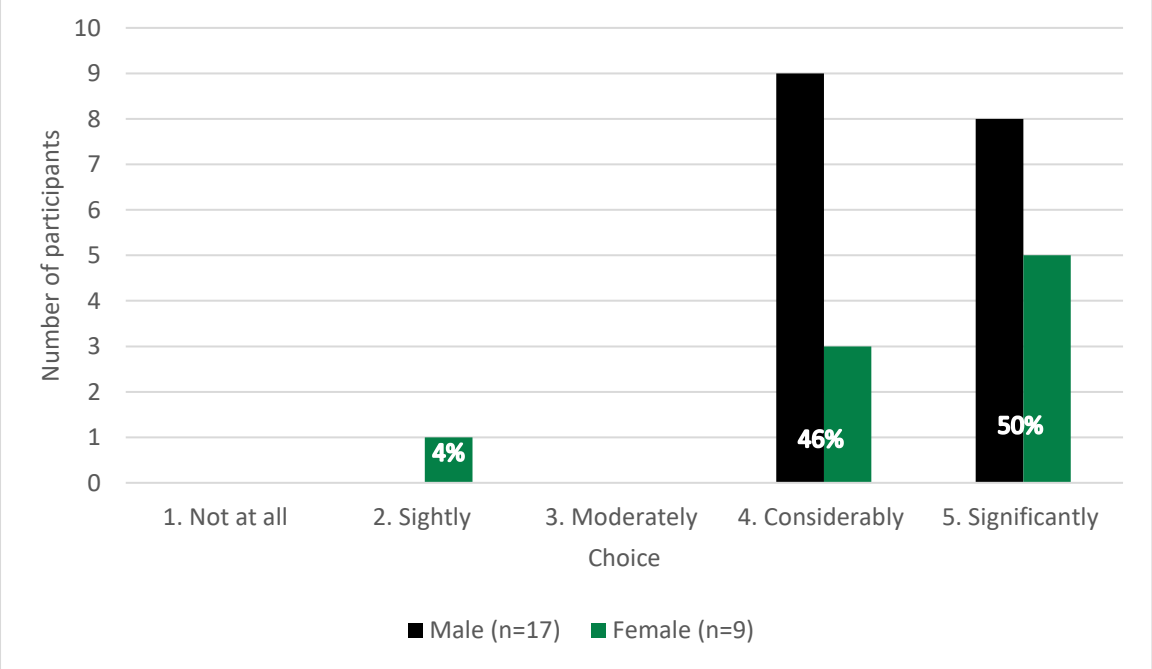


Figure 2

How much did your knowledge about aquaponics improve after the virtual reality tour?



Food Safety Knowledge.

Participants' familiarity with food safety was somewhat higher than with aquaponics prior to the tour, although many still rated their knowledge as moderate and very familiar (38.4%) (Figure 3). After the tour, 92.3% reported an increase in food safety knowledge (Figure 4). A study conducted by Lee et al. (2022) on virtual reality food safety training specifically in safe handling showed that the inclusion of pre-recorded 360-degree videos, along with additional 2D video content and interactive elements, provided learners with an immersive real-world experience. Additionally, it offered individuals the opportunity to test their food safety knowledge in a realistic setting, and the use of the virtual reality food safety application helped users recognize and identify mistakes in a real-world environment.

Figure 3

How familiar were you with food safety concepts before the virtual reality tour?

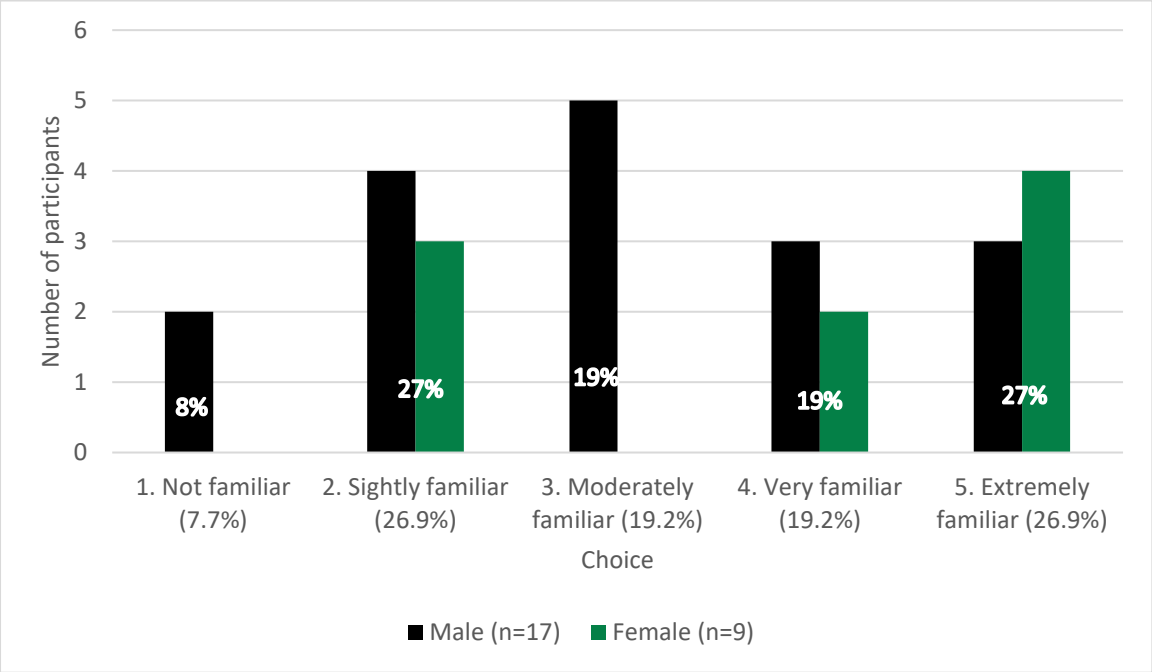
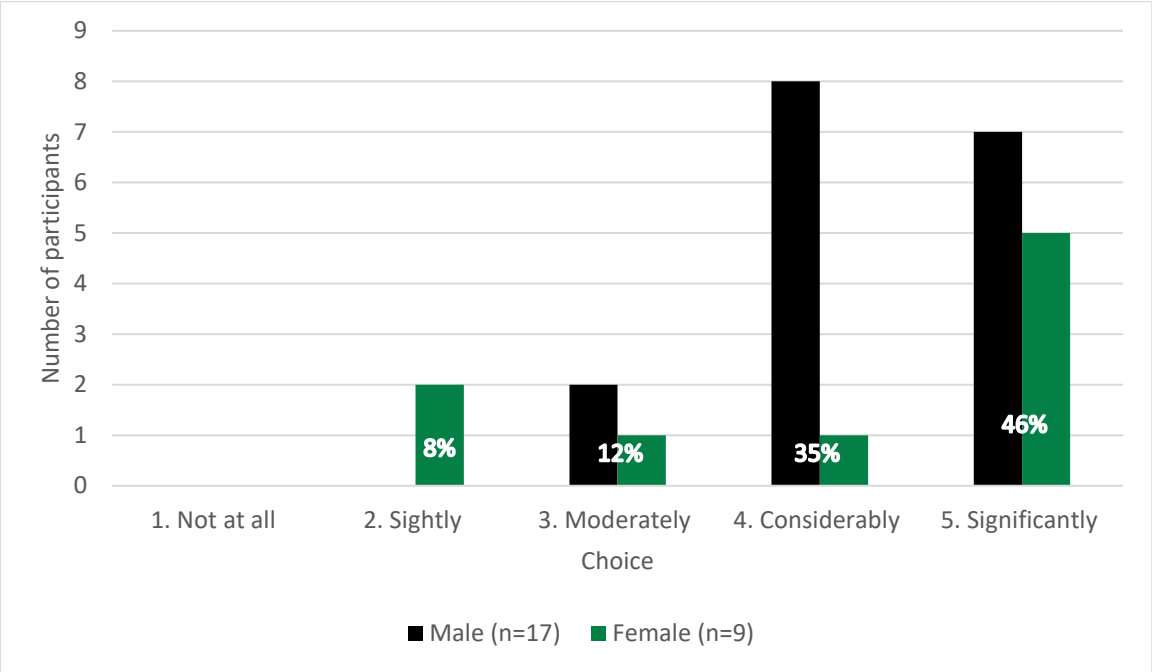


Figure 4

How much did your knowledge about food safety improve after the virtual reality tour?



Interest in Food Safety and Aquaponics.

A combined 77% (Figure 5) of participants stated that the tour considerably or significantly increased their interest in food safety. This suggested that beyond knowledge transfer, the VR experience was engaging enough to inspire further interest in the topic. 73.1% of participants reported a considerable or significant increase in their interest in aquaponics (Figure 6). This demonstrated the tour's success not only in teaching, but also in generating curiosity and motivation to learn more about sustainable food production systems.

According to a study conducted by Schütz et al. (2022) on virtual reality tours in pig farming, the experience was perceived as entertaining through both multimedia devices (VR glasses and tablets), which was considered likely to increase people's interest in the topic especially in the case of the virtual reality glasses. Similar effects were observed in the field of agricultural education, where virtual reality had an enriching impact on learning processes by increasing students' overall interest in the educational content and facilitating the understanding of various topics.

Figure 5

How much do you think the tour increased your interest in food safety?

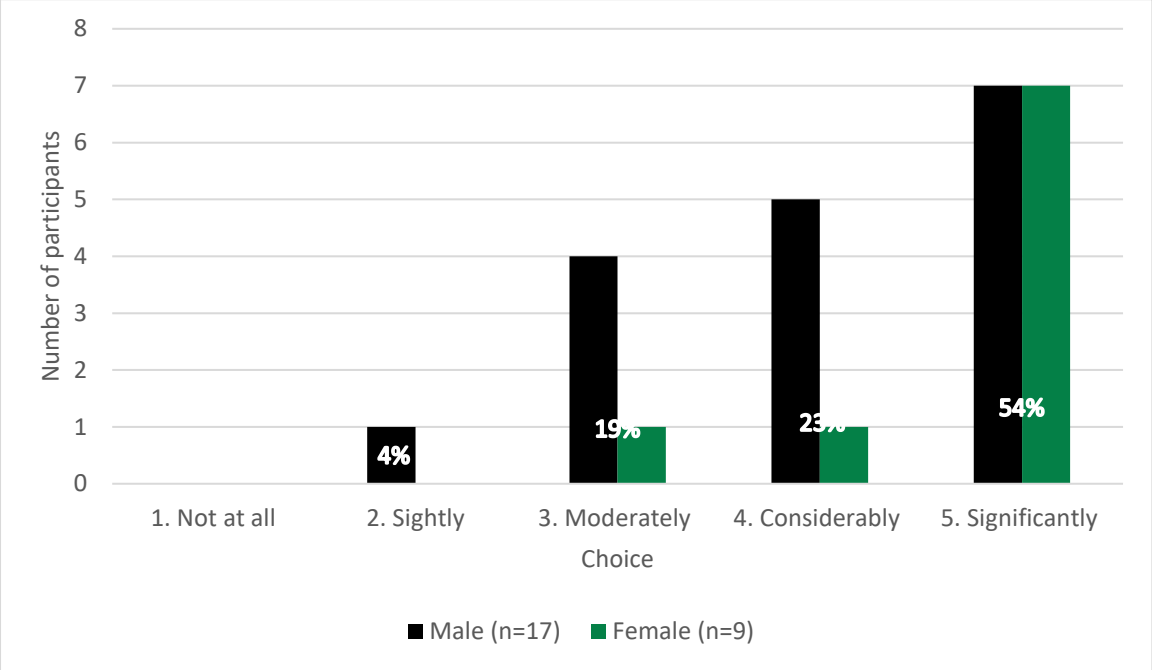
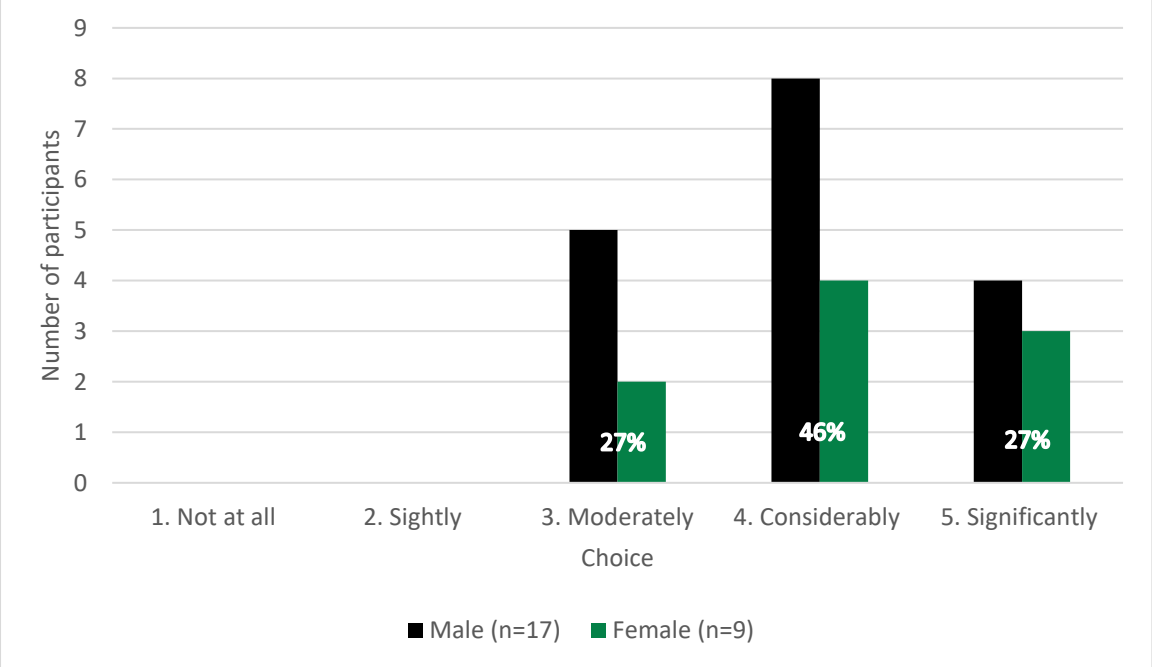


Figure 6

How much do you think the tour increased your interest in aquaponics?



VR as Educational Tool.

A strong 76.9% (Figure 7) of participants indicated that the virtual farm tour was "very likely" to be used as an effective educational tool for aquaponics. This validated the tour's potential as a complementary or alternative method to conventional teaching methods in agricultural topics. About 77% said it was “very likely” to be a good learning tool (Figure 8). This means the content and format were effective.

Allison and Hodges (2000) developed a virtual reality system to explore how this technology could be used to help high school students acquire knowledge and form concepts. They created a trial virtual reality system to teach participating students about gorillas, and the results showed that the system had potential as a public education tool. Through the study, they realized that there were not enough resources to generate meaningful content, but they remained optimistic that, once content creation and appropriate hardware became economically viable, virtual reality would be highly useful in public education.

Figure 7

How likely do you think the virtual farm tour could be used as a learning tool to improve knowledge about aquaponics farm?

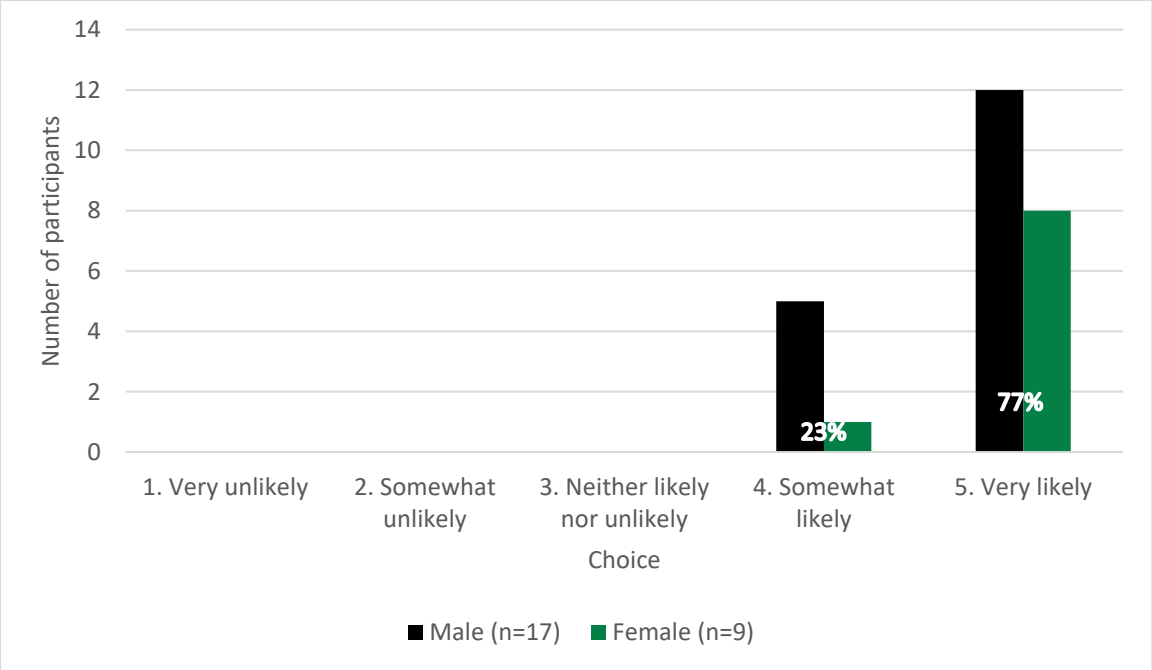
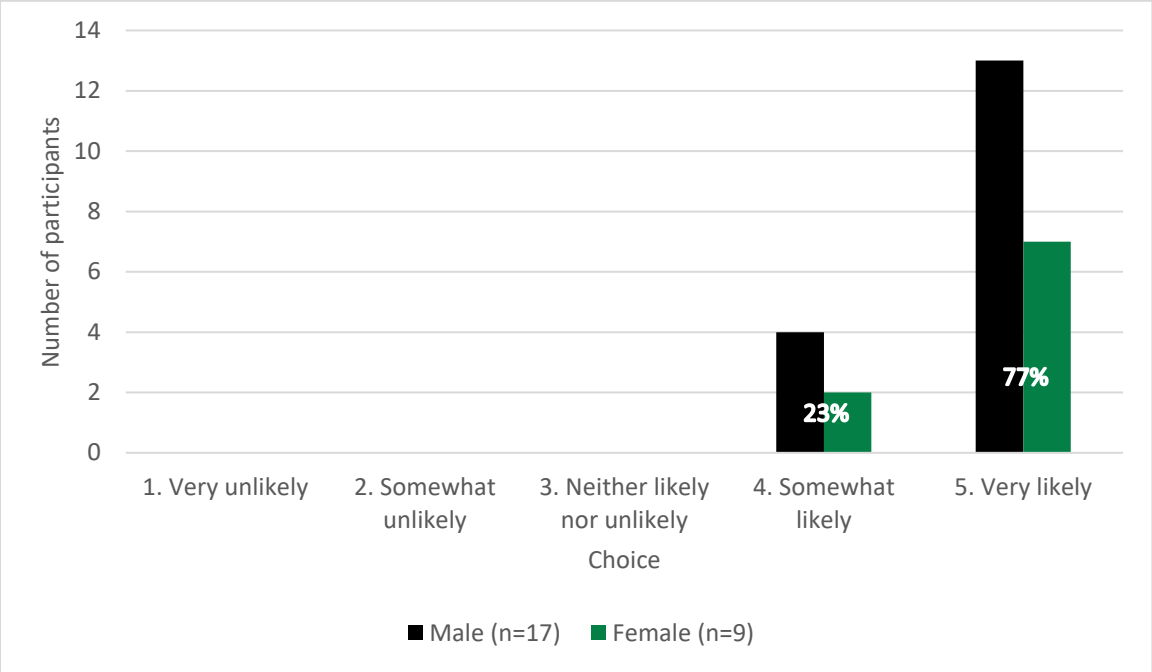


Figure 8

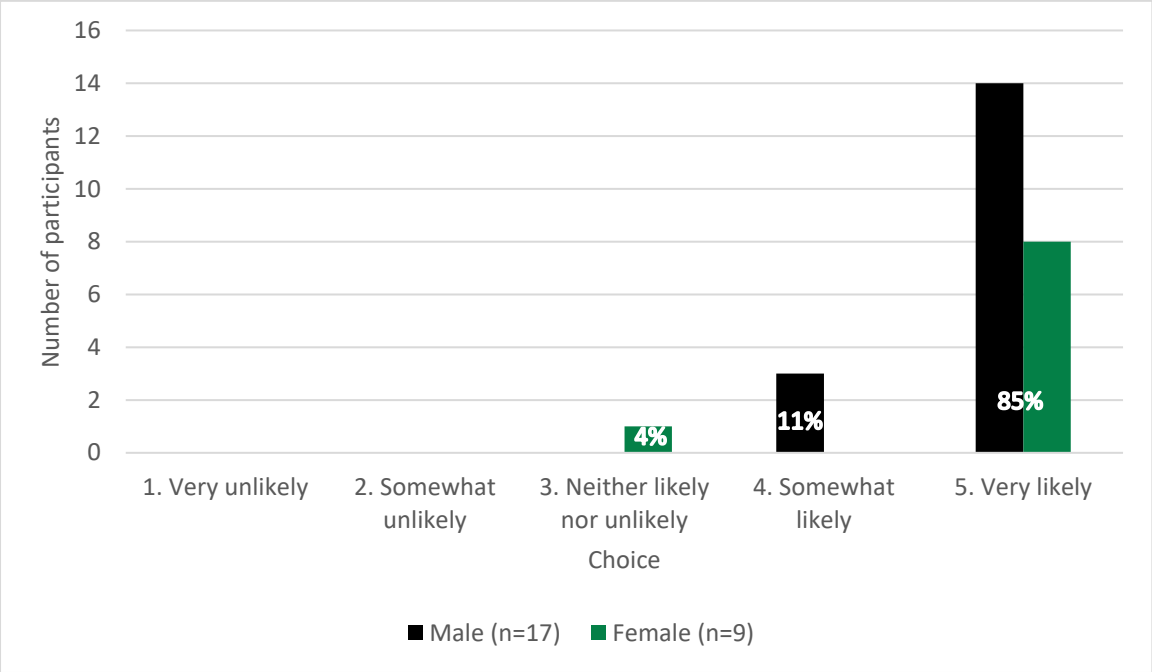
How likely do you think the virtual farm tour could be used as a learning tool to improve knowledge about food safety?



More than 84% of participants said the tour could help consumers understand how farming works (Figure 9). This has important implications for public awareness and could support more informed consumer choices regarding food origin and production methods. Sutherland et al. (2020) found that consumers lacked basic knowledge in most areas of agricultural production through a survey of 700 participants from across English-speaking Canada. They recommended that the agriculture industry should improve its education and communication efforts with consumers. And VR has been shown to be a functional tool for education due to the immersive and interactive experience that users have.

Figure 9

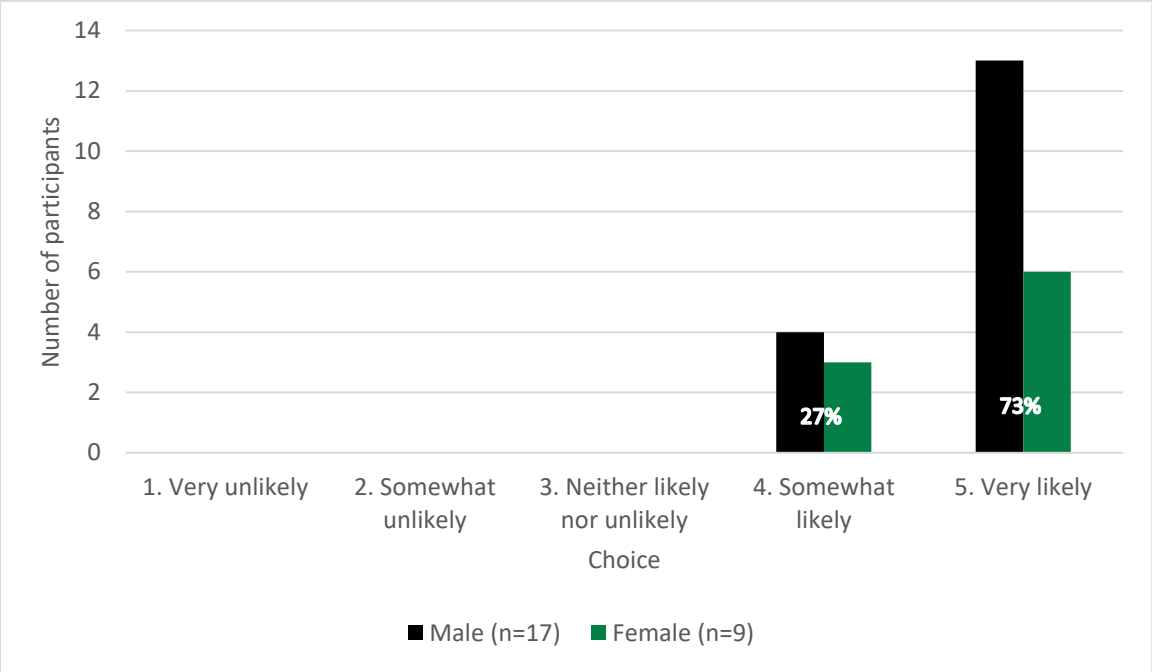
How likely do you think this virtual reality tour can help consumers to better understand farming practices?



Most participants (73%) also believed that the virtual tour could change how people think about farming (Figure 10). This showed that technology like VR can connect people more with agriculture and food systems. Nguyen et al. (2023) conducted a similar study on a dairy farm, and their results showed that the developed system was perceived as an effective and useful learning tool for providing authentic information to consumers, while also encouraging them to learn more about the dairy farm and the industry. Moreover, they stated that this approach helped deliver accurate information about agricultural production to consumers so they could understand how farmers produced the food they eat and, in turn, build trust in the industry.

Figure 10

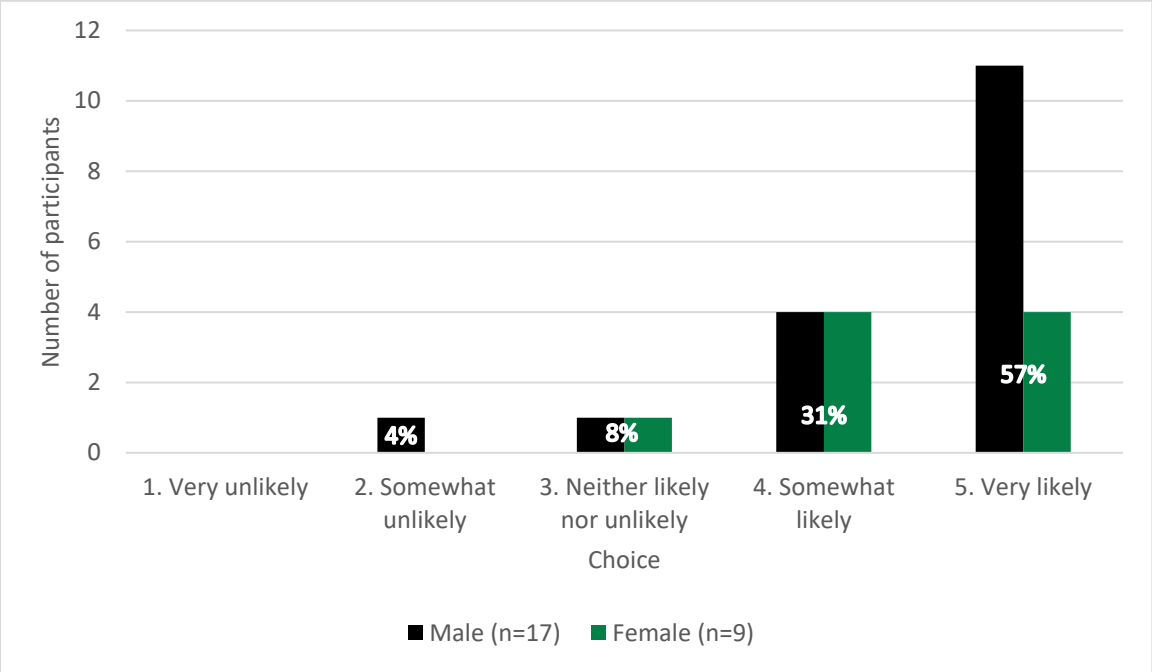
How likely experiencing a virtual reality tour could change consumers' perceptions on farming and agriculture?



57.7% of participants considered the VR tour a “very likely” alternative to in-person training (Figure 11). This illustrated VR as a promising option in cases where physical access to farms is limited due to distance, safety, or cost. Jensen and Konradsen (2018) proposed a paper where they introduced an innovative approach to integrating Virtual Reality into the educational process to cater to the demands of industry. The study meticulously examined the merits and drawbacks of VR-based education, significantly influencing its applicability and relevance. Furthermore, the paper showcased the training outcomes conducted through this VR system. The results demonstrated the immense potential of virtual environments for enhancing participants’ skills and knowledge.

Figure 11

How likely do you think the virtual reality farm tour could be an alternative to an in-person farm tour for training?



Second Phase

Demographic Characteristics

A total of 100 participants completed the Virtual Reality Aquaponic Greenhouse Tour (laptop version). Gender distribution was balanced, with 49 males and 51 females. Most participants were between 18 and 21 years of age, with the largest group being 20 years old (26%), followed by 18 years (23%) and 21 years (20%). The participants represented nine countries, with the highest proportions from El Salvador (27%) and Ecuador (22%), followed by Honduras (19%) and Guatemala (18%).

In terms of academic level, most students were in their fourth year (31%) or third year (30%), while 25% were in their first year and 14% in their second year. Regarding majors, the majority were in environmental sciences (22%) and agricultural sciences (17%), followed by food science (14%) and agribusiness (8%) (Table 5).

Table 5

Demographic characteristics of the Virtual Reality Aquaponic Greenhouse Tour (laptop version).

Characteristics	Total n (n =100)
Gender	
Male	49
Female	51
Age	
18	23
19	17
20	26
21	20
22	13
23	1
Country	
Belice	1
Bolivia	2
Ecuador	22
El Salvador	27
Guatemala	18
Honduras	19
Nicaragua	8
Panama	2
Peru	1
Year	
First year	25
Second year	14
Third year	30
Fourth year	31
Major	
General Education	39
Food Science and Technology (AGI)	14
Environmental Science and Development (IAD)	22
Agricultural Sciences (CPA)	17
Agribusiness Management (AGN)	8

Quiz Tour Results

The results of the Pre-Tour Knowledge Assessment (Table 6) showed that participants had different levels of knowledge before beginning the virtual tour to the aquaponic greenhouse. In the system section, more than half of the participants answered the first question correctly (53%), while performance improved in the second question (81%), indicating a partial understanding of the topic.

In the plant section, performance was lower. Only 43% answered the first question correctly, and 37% responded correctly to the third question. In the section on fish, high scores were observed

in the first two questions (89% and 88% correct answers), while the third question obtained a lower result (71%). It was observed that participants had a general knowledge of fish production.

In the food safety section, results were mixed. While 77% of participants answered the first question correctly, only 60% answered the second question correctly. Overall, the pre-tour quiz results demonstrated that participants had a fragmented knowledge of aquaponics and food safety, with stronger understanding in some areas such as system and fish.

Table 6

Results of correct and incorrect answers on the pre tour quiz.

Section	Total correct answer (n =100)	Total incorrect answer (n =100)
System		
Question 1	53	47
Question 2	81	19
Plant		
Question 1	43	57
Question 2	90	10
Question 3	37	63
Fish		
Question 1	89	11
Question 2	88	12
Question 3	71	29
Food safety		
Question 1	77	23
Question 2	60	40

The results of the tour quiz (Table 7) showed a significant improvement in knowledge in all sections. In the system section, almost all participants (97%) answered the first question correctly, with only 3% giving incorrect answers. The section on plants showed some persistent difficulties, as questions 1 and 3 continued to be challenging for some participants. While knowledge related to fish showed a notable improvement compared to the previous quiz, question 3 was still a challenge for 22% of participants. Most significantly, the food safety section showed considerable progress in learning, with only 5% of respondents answering question 2 incorrectly.

Bellamy and Warren (2011) conducted a case study using simple online interactive simulations which mimicked real experiments. Eighty-three percent of their students reported that they found these online simulations helpful or very helpful, and their demonstrators stated that the students

seemed much better prepared and more willing to answer questions when they had done the online simulations. These and other examples promote learning the usefulness of simulated environments as alternatives to real-life scenarios. This demonstrated that virtual reality can be a useful tool for increasing knowledge in different areas, and as could be seen, the results after the virtual tour improved significantly.

Table 7

Results of correct and incorrect answers on the quiz during the tour.

Section	Total correct answer (n =100)	Total incorrect answer (n =100)
System		
Question 1	97	3
Question 2	100	-
Plant		
Question 1	83	17
Question 2	100	-
Question 3	80	20
Fish		
Question 1	96	4
Question 2	91	9
Question 3	78	22
Food safety		
Question 1	100	-
Question 2	95	5

The t-test analysis (Table 8) demonstrated statistically significant improvements in quiz performance across the years ($p < 0.05$). Participants showed an increase in the mean score for correctly answered questions (10 questions from the 4 sections of the quiz) when comparing the results of the pre-tour quiz with those obtained during the tour. First year students showed a mean increase of 2.04 points (from 7.20 to 9.24), second year improved by 2.57 points (7.00 to 9.57), third year increased by 2.66 points (6.77 to 9.43), and fourth year gained 2.26 points (7.26 to 9.52) (Table 8). Mount et al. (2009) suggested that engagement and immersion in virtual environments tend to be more effective when learners have higher cognitive maturity because they can link new concepts to existing knowledge. In this study, all academic years showed significant improvement, however third year and fourth year students began with higher baseline scores and also achieved strong post-tour results. This pattern can be attributed to their prior exposure to agricultural concepts, combined with

the development of greater academic maturity, which improved their ability to understand and hold onto complex information more effectively.

Table 8

t-Test analysis of correct responses by year.

Year	Pre-tour quiz (Mean ± SD)	Tour quiz (Mean ± SD)	t Value	p Value
First year	7.20±1.96	9.24±0.93	-6.02	<.0001
Second year	7.00±1.84	9.57±0.51	-5.52	<.0001
Third year	6.77±1.79	9.43±0.77	-8.65	<.0001
Fourth year	7.26±1.69	9.52±0.72	-6.57	<.0001
Total	6.91±2.11	9.25±0.97	-3.49	0.0021

Further analysis by major (Table 9) showed that all majors experienced statistically significant improvements. Food Science students improved their scores from 7.20 ± 1.86 to 9.73 ± 0.59 ($p = 0.0004$), Agribusiness Management students from 6.50 ± 1.69 to 9.63 ± 0.52 ($p = 0.0010$), Agricultural Science students from 7.12 ± 1.73 to 9.29 ± 0.85 ($p < 0.0001$), and Environmental Science students from 7.05 ± 1.76 to 9.41 ± 0.80 ($p < 0.0001$). The pre-quiz results in this study were already relatively high, which may be explained by the academic background of participants. Nguyen et al. (2023) emphasized that consumers and individuals outside agricultural education typically have misconceptions about farming practices, which virtual reality interventions aim to correct. Therefore, students in agriculture-related and food safety majors, like those in this study, may start with stronger baseline knowledge because their programs already include concepts of food safety and aquaponics greenhouse. This context helps explain why the improvement after the VR tour, although significant, started from a higher initial level compared to other majors.

Table 9

t-Test analysis of correct responses by year major.

Major	Pre-tour quiz (Mean ± SD)	Tour quiz (Mean ± SD)	t Value	p Value
Food Science	7.20±1.86	9.73±0.59	-4.60	0.0004
Agribusiness Management	6.50±1.69	9.63±0.52	-5.38	0.0010
Agricultural Science	7.12±1.73	9.29±0.85	-6.50	<.0001
Environmental Science	7.0.5±1.76	9.41±0.80	-5.79	<.0001

In terms of gender (Table 10), both female and male students also showed statistically significant increases in performance. Female students improved their average scores from 7.04 ± 1.91 to 9.53 ± 0.70 ($p < 0.0001$), while male students increased from 7.00 ± 1.72 to 9.33 ± 0.83 ($p < 0.0001$).

A similar study conducted by Woon et al. (2021) examined the effectiveness of virtual reality (VR) in enhancing knowledge acquisition among nursing students, with a total sample of 975 participants. The results showed significantly higher knowledge scores in the VR group compared to the control group (standardized mean difference = 0.48; 95% CI: 0.13 to 0.84; Z = 2.66; p = 0.01), indicating a small to medium effect size (g = 0.47) based on a random effects model. The findings demonstrated that VR training significantly improved knowledge levels in nursing education. VR increased student engagement in the learning experience by allowing them to participate in experiences close to reality, a feature which can explain the improved knowledge scores.

Table 10

t-Test analysis of correct responses by gender.

Gender	Pre-tour quiz (Mean ± SD)	Tour quiz (Mean ± SD)	t Value	p Value
Female	7.04±1.91	9.53±0.70	-9.62	<.0001
Male	7.00±1.72	9.33±0.83	-9.72	<.0001

Survey Results

The 100 participants completed a 47-question survey after finishing the VR tour, reflecting their perceptions of the effectiveness of the virtual farm visit as an educational tool for promoting knowledge about food safety and aquaponics.

Aquaponics Knowledge.

First and third year participants reported limited familiarity with aquaponics prior to the tour (Figure 12), with most indicating they were either 'not familiar' (15%) or 'slightly familiar' (16%). In contrast, a greater proportion of third- and fourth-year participants reported being 'moderately familiar' (18%) or 'very familiar' (13%) with aquaponic. After the virtual tour, students from first to

fourth year responded that their knowledge of aquaponics had improved. Results (Figure 13), and 10% moderately

Figure 12

How familiar were you with aquaponics before the virtual reality tour?

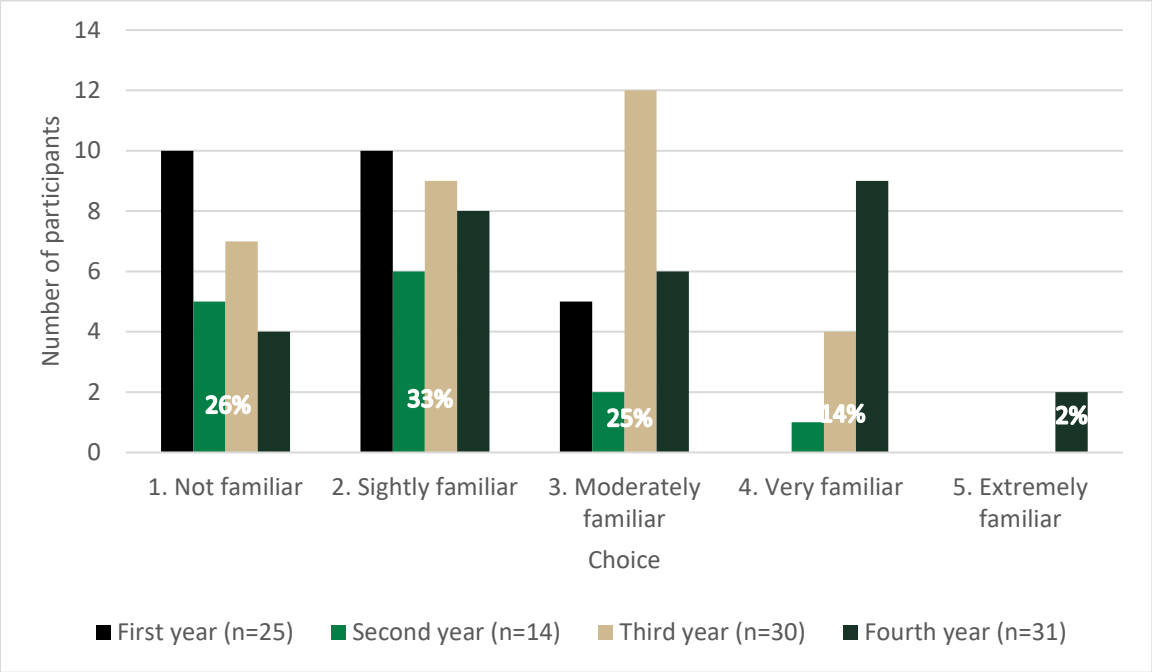
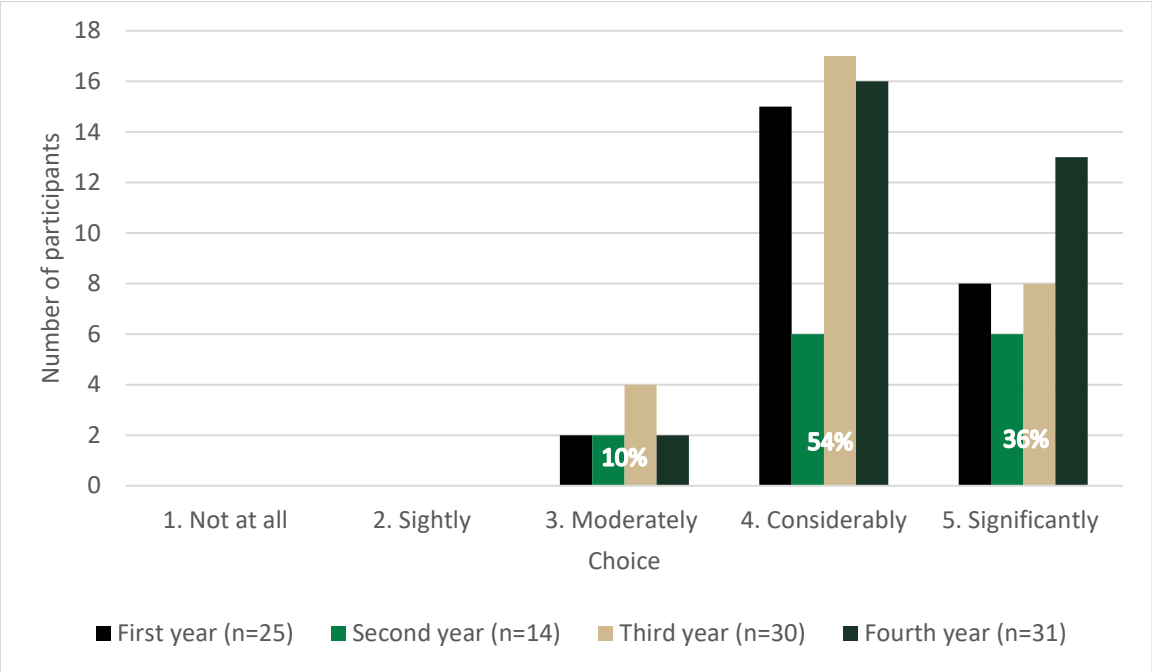


Figure 13

How much did your knowledge about aquaponics improve after the virtual reality tour?



Food Safety Knowledge.

Before the virtual tour, many students reported having limited knowledge about food safety concepts (Figure 14). Nearly half of the participants (49%) said they were either not familiar (25%) or slightly familiar (24%), most of the participants from first year and second year. After the virtual reality tour, most students answered that their understanding of food safety had improved noticeably (Figure 15). A combined 84% of participants said their knowledge increased either considerably (45%) or significantly (39%). Another 15% reported a moderate improvement, and only one student indicated a slight gain. These results showed that the virtual tour was an effective and engaging way to help students learn more about aquaponics and food safety, regardless of their starting level of knowledge (Bicalho et al., 2023).

Figure 14

How familiar were you with food safety concepts before the virtual reality tour?

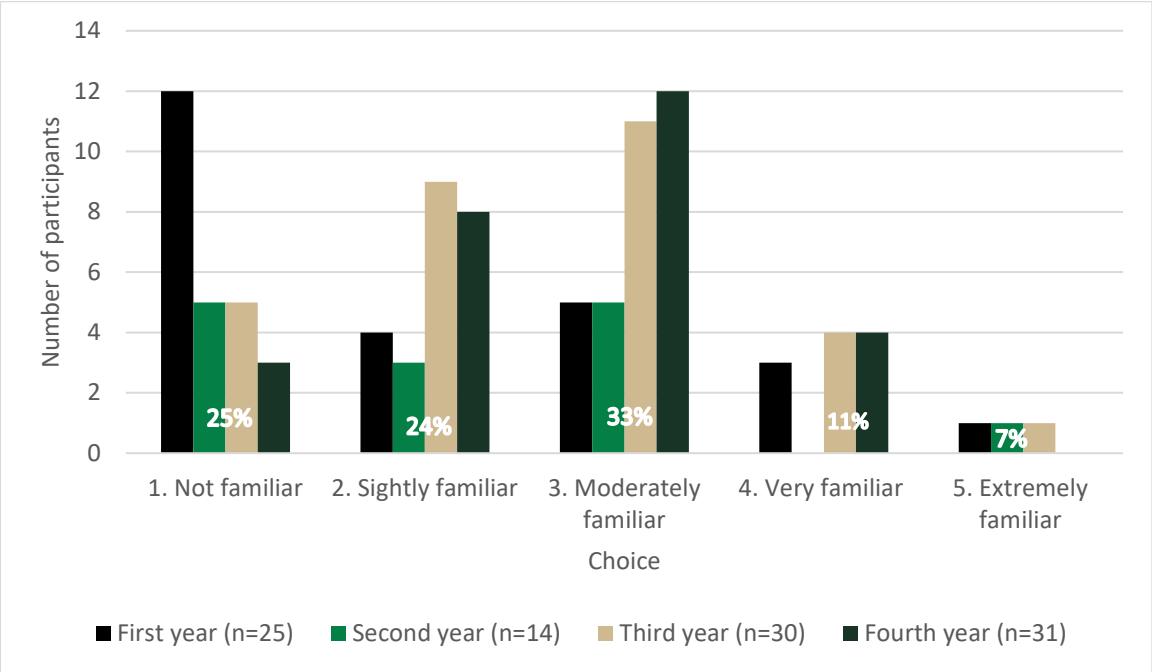
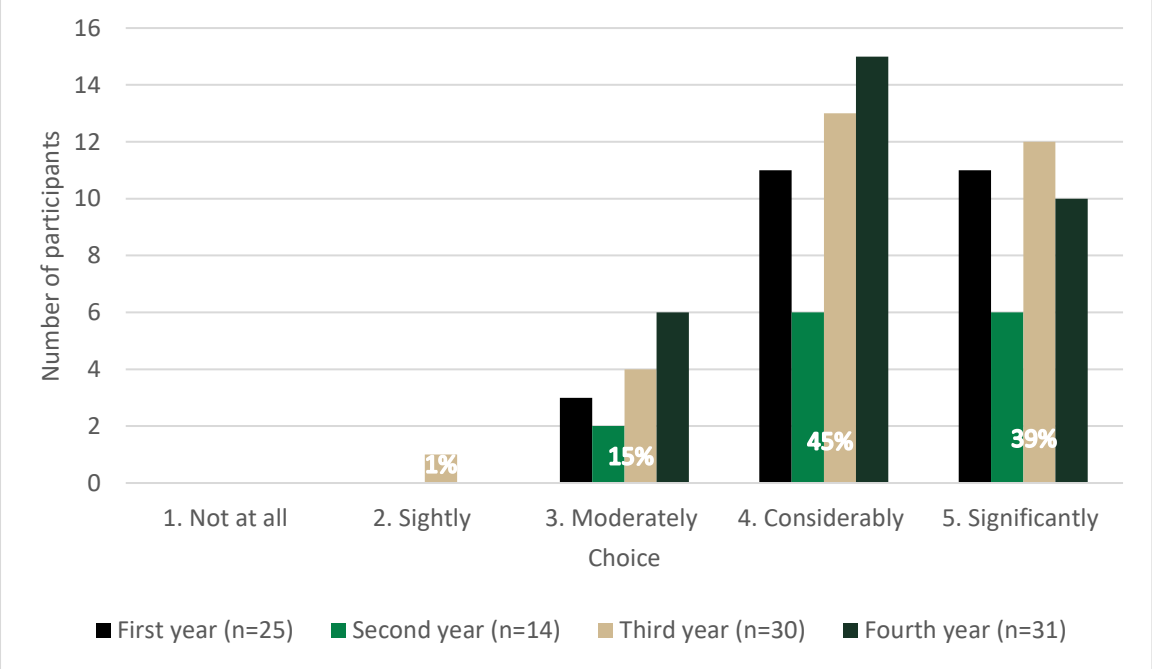


Figure 15

How much did your knowledge about food safety improve after the virtual reality tour?



Interest in Food Safety and Aquaponics.

Students from the four years reported that the virtual reality (VR) tour increased their interest in food safety and aquaponics. Regarding food safety (Figure 16), 46% of participants said their interest increased considerably and 40% said it increased significantly. Moderate increases were reported by 14%. Similarly, interest in aquaponics (Figure 17), with 44% of students reporting a significant increase and 39% a considerable increase. Moderate increases were seen in 17%. Bicalho et al. (2023) mentioned that it is possible to observe that the use of immersive virtual reality in practical experiences has demonstrated the technology's ability to create three-dimensional virtual environments that promote enriching learning experiences for students and increase interest in different environments.

Figure 16

How much do you think the tour increased your interest in food safety?

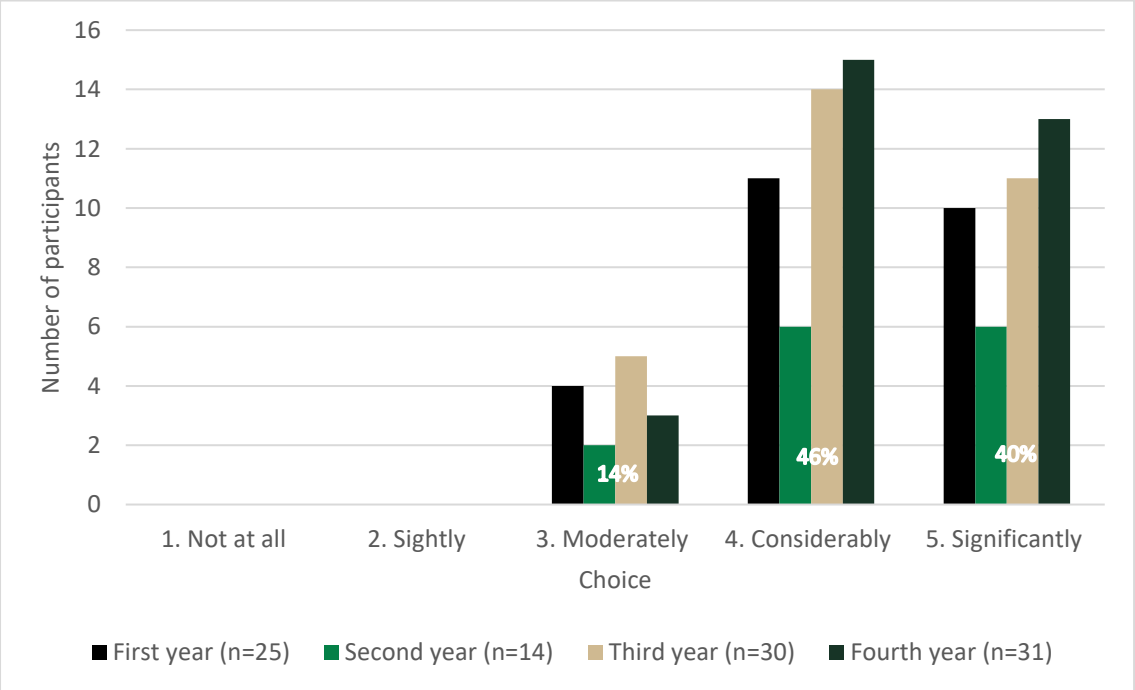
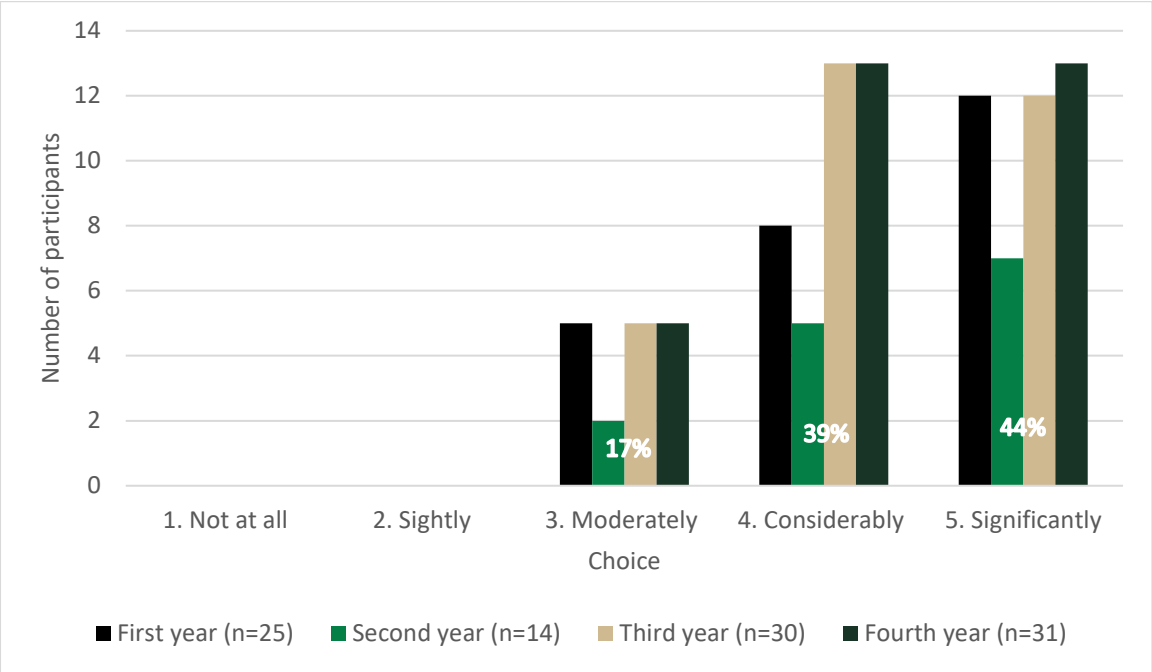


Figure 17

How much do you think the tour increased your interest in aquaponics?



VR as Educational Tool.

When asked about the potential of the virtual farm tour as a learning tool, most students thought it to be effective. For improving knowledge about aquaponics (Figure 18), 71% of participants said it was somewhat likely and 29% very likely to be useful. Similarly, for food safety knowledge (Figure 19), 86% rated the tour as somewhat likely and 13% very likely to help learning, with almost no negative responses. Gaytan and McEwen (2007) concluded that it is beneficial to use a variety of instructional methods to appeal to students' learning preferences. VR activities could be designed to include multiple learning methods, so learners can choose to engage with the learning materials in the manner that interests them the most.

Figure 18

How likely do you think the virtual farm tour could be used as a learning tool to improve knowledge about aquaponics farm?

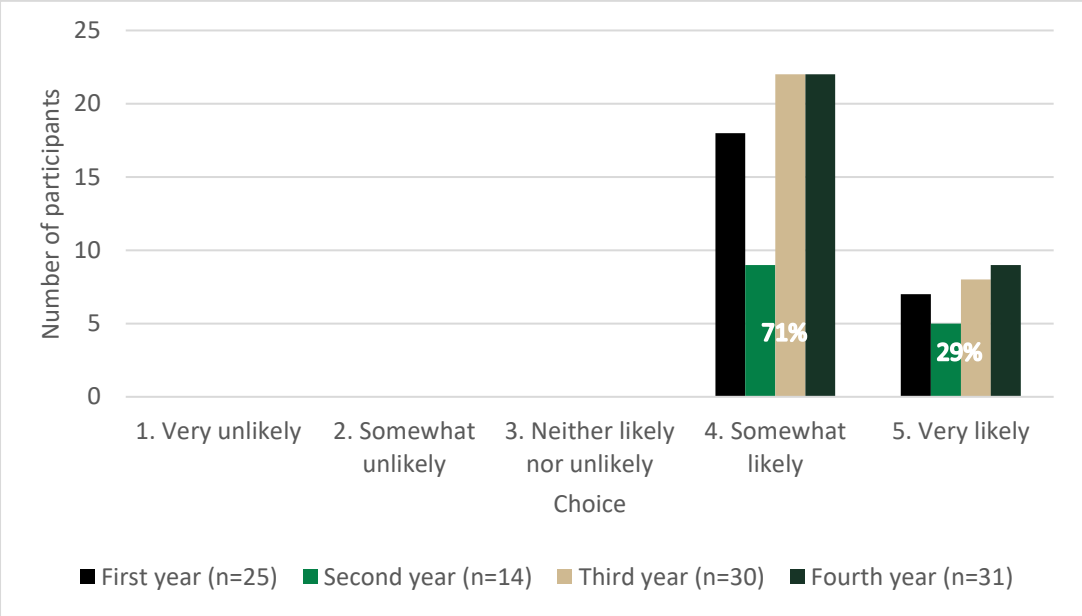
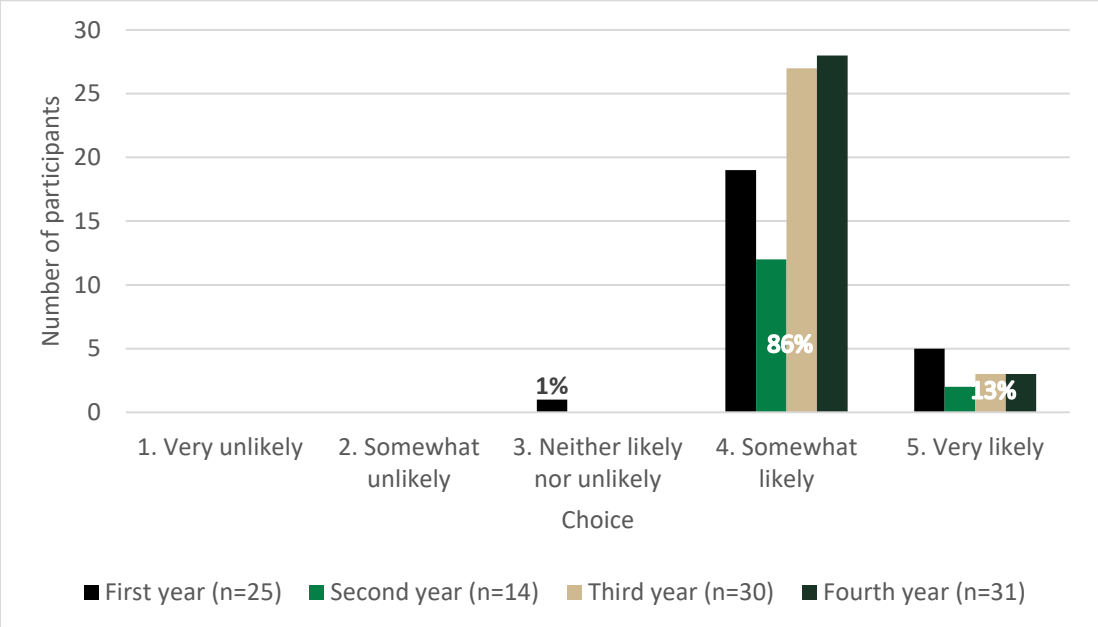


Figure 19

How likely do you think the virtual farm tour could be used as a learning tool to improve knowledge about food safety?



Regarding the tour's ability to help consumers understand farming practices (Figure 20), 77% of participants thought it was somewhat likely and 20% very likely to have a positive impact. This perception extended to changing consumer views on farming and agriculture (Figure 21), where 78% rated the effect as somewhat likely and 20% very likely. Mount et al. (2009) discussed the relationship between immersion, presence and engagement. They explored what it means for a learner to be immersed and considered immersion and engagement in 3D virtual environments, to outline how 3D virtual environments can be used to enhance learner engagement and understand different topics better.

Figure 20

How likely do you think this virtual reality tour can help consumers to better understand farming practices?

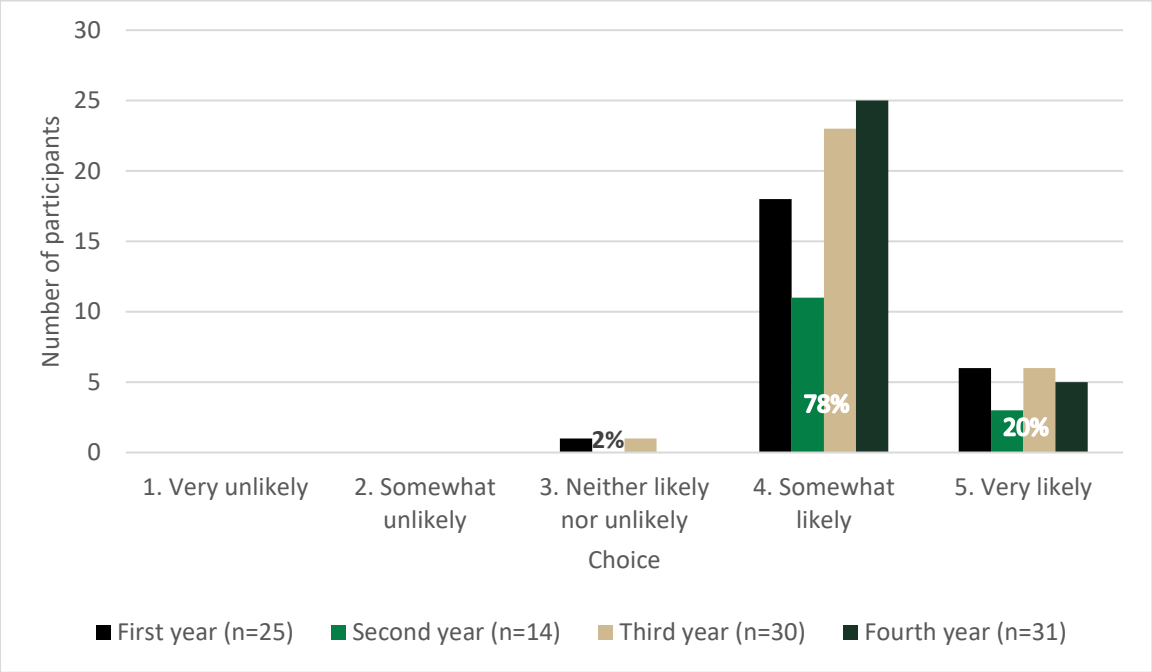
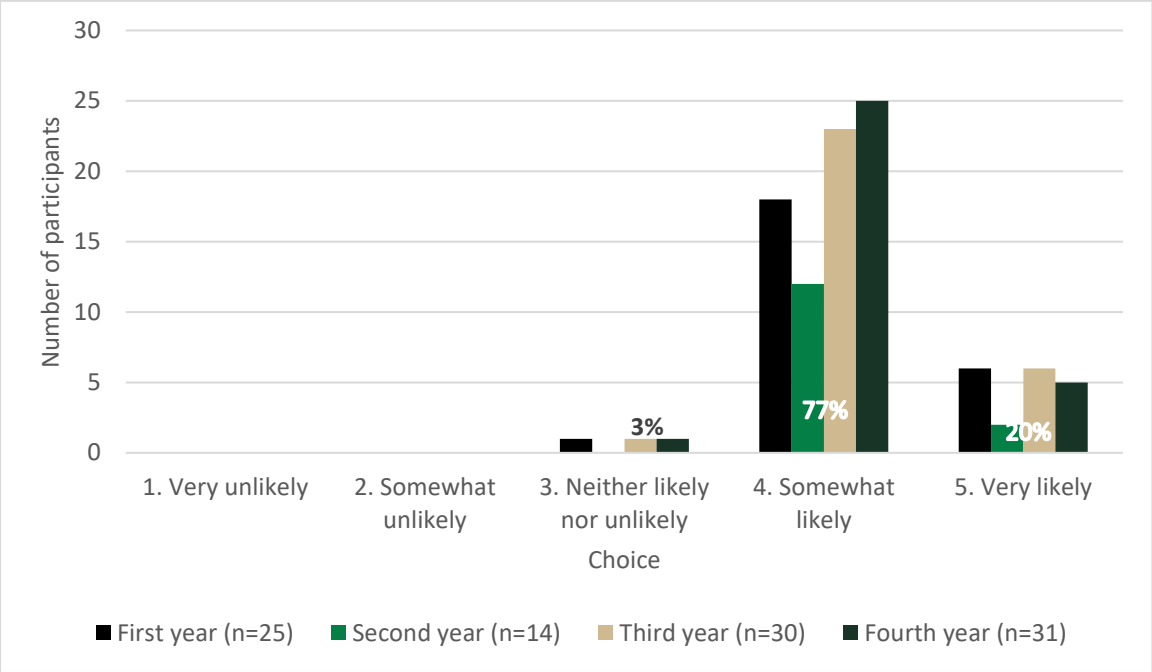


Figure 21

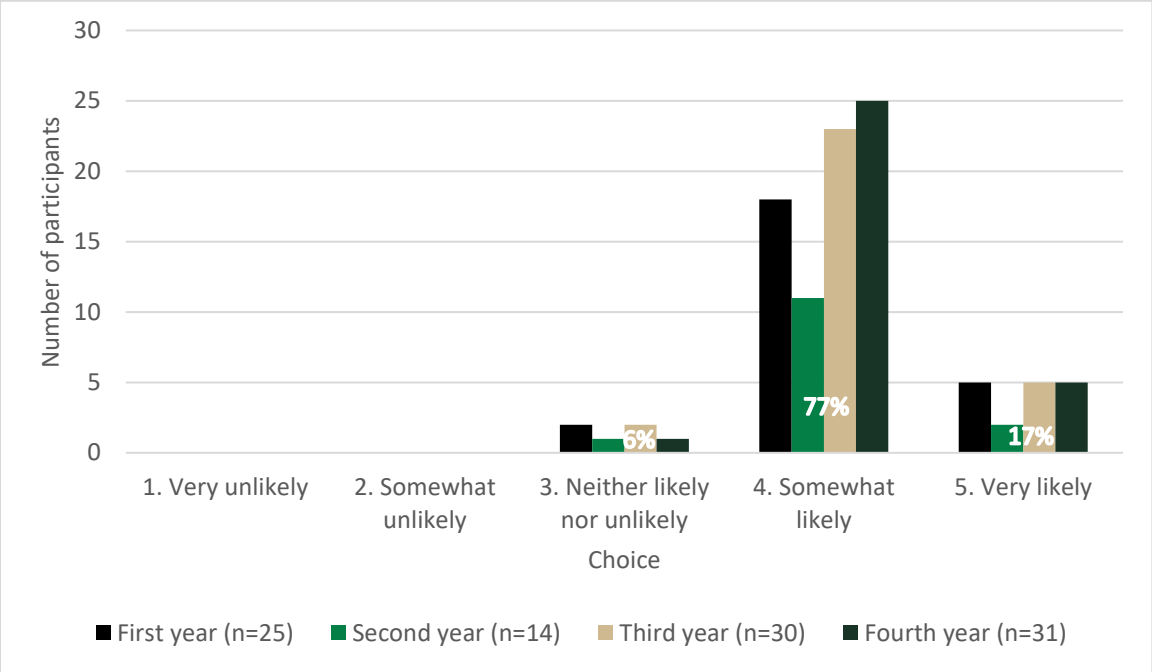
How likely experiencing a virtual reality tour could change consumers' perceptions on farming and agriculture?



When considering the VR tour as an alternative to an in-person farm tour for training (Figure 22), most participants again responded positively: 77% said it was somewhat likely and 17% very likely to serve as a substitute, with only 6% neutral. VR teaching and training can provide information close to real-life situations offering multiple means of visualization and analysis and providing learners with a safe training environment to acquire specific skills and competences) in alternative to real-life contexts (Santilli et al., 2025).

Figure 22

How likely do you think the virtual reality farm tour could be an alternative to an in-person farm tour for training?



Conclusions

The study concluded that the virtual reality tour was highly effective in improving participants' knowledge and interest in aquaponics and food safety. A significant increase in knowledge was observed in both phases of the study, regardless of the participants' prior familiarity with these areas. Participants showed a high comprehension of the material, with quiz results demonstrating a significant improvement in knowledge in all sections after the tour. In the second phase, students from all years, majors and gender showed a statistically significant increase in their quiz scores from before to after the tour.

The analysis demonstrated that a virtual reality (VR) tour was an effective tool for improving food safety education. The study showed that VR tours not only enhanced participants' knowledge but also increased their interest in food safety and aquaponics.

The research highlighted the potential of a VR tour to increase participants' knowledge and understanding of aquaponic systems as an alternative to in-person farm tours. The results showed that participants’ knowledge about aquaponics and food safety improved significantly after the tour. Most participants also considered the virtual tour a viable alternative to an in-person farm tour for training purposes.

Recommendations

It is recommended to include virtual reality in food safety training programs to make them more practical and attractive for different audiences. The VR approach should focus not only on theoretical requirements but also on practical application in various agricultural contexts, as has been shown to improve knowledge and interest in the topic. VR training can be made accessible to a broader audience, regardless of their location, facilitating continuous education and providing digital resources adapted to specific needs.

VR can also be used to reduce barriers such as distance or cost, and to help raise awareness about food safety among the public. The study found that VR is a viable alternative to in-person farm tours for training, particularly in cases where physical access is limited due to distance, cost, or safety. Furthermore, VR can be used to provide consumers with accurate information about farming practices, which can build trust in the agricultural industry and potentially change their perceptions of how food is produced.

It is suggested to facilitate the development of advanced VR content specifically for food safety. The immersive and interactive nature of VR can be utilized to create engaging experiences that help users identify and understand food safety risks and proper hygiene practices. Future VR programs should focus on challenging topics to enhance knowledge retention and ensure that the adoption of these technologies is promoted through targeted training programs and to make them accessible to all.

References

Allison, D., & Hodges, L. F. (2000). Virtual reality for education? In H. Kimn & K. Yun (Eds.), *Proceedings of the ACM symposium on Virtual reality software and technology* (pp. 160–165). ACM. https://doi.org/10.1145/502390.502420

Almahasees, Z., Mohsen, K., & Omer, M. (2021). Faculty's and Students' Perceptions of Online Learning During COVID-19. *Frontiers in Education*. https://www.researchgate.net/publication/351525235_Faculty's_and_Students'_Perceptions_of_Online_Learning_During_COVID-19

Bellamy, M., & Warren, A. (2011). *Using Online Practicals To Support Lab Sessions*. https://es.scribd.com/document/481195377/Online-Practicals-to-Support-Labs-Matthew-Bellamy

Bicalho, D., Piedade, J., & Lacerda, J. (2023). *The Use of Immersive Virtual Reality in Educational Practices in Higher Education: A Systematic Review*. https://ieeexplore.ieee.org/abstract/document/10423711/authors#authors

Bowman, D., & McMahan, R. (2007). Virtual Reality: How Much Immersion Is Enough? *ResearchGate*, *40*(7), 36–43. https://www.researchgate.net/publication/2961880_Virtual_Reality_How_Much_Immersion_Is_Enough

Chang, M. (2022). International Journal of Distance Education Technologies (IJDET): 1539-3100, 1539-3119: Education Journals | IGI Global Scientific Publishing. *International Journal of Distance Education Technologies*, *10*(2), 1–16. https://www.igi-global.com/journal/international-journal-distance-education-technologies/1078

Dahiya, V. (2024). Virtual Reality And Inclusive Education: A Qualitative Exploration Of Transformative Technologies. *Educational Administration: Theory and Practice*, *30*(4), 2017–2022. https://doi.org/10.53555/kuey.v30i4.1798

Gaytan, J., & McEwen, B. (2007). Effective Online Instructional and Assessment Strategies, *21*(3), 117–132. https://www.researchgate.net/publication/242592681_Effective_Online_Instructional_and_Assessment_Strategies

Greenfeld, A., Becker, N., McIlwain, J., Fotedar, R., & Bornman, J. F. (2019). Economically viable aquaponics? Identifying the gap between potential and current uncertainties. *Reviews in Aquaculture*, *11*(3), 848–862. https://doi.org/10.1111/raq.12269

Insfran-Rivarola, A., Tlapa, D., Limon-Romero, J., Baez-Lopez, Y., Miranda-Ackerman, M., Arredondo-Soto, K., & Ontiveros, S. (2020). A Systematic Review and Meta-Analysis of the Effects of Food Safety and Hygiene Training on Food Handlers. *Foods*, *9*(9), 1169. https://doi.org/10.3390/foods9091169

Jensen, L., & Konradsen, F. (2018). A review of the use of virtual reality head-mounted displays in education and training. *Education and Information Technologies*, *23*, 1515–1529. https://link.springer.com/article/10.1007/S10639-017-9676-0#citeas

Lee, L., Nisar, H., Roberts, J., Blackford, J., & Kesavadas, T. (2022). *Face and Content Validation of Food Safety Training in Virtual Reality (VR) | IEEE Conference Publication | IEEE Xplore*.

https://ieeexplore.ieee.org/abstract/document/9978588?casa_token=GdGffZ5qargAAAAA:i_faf938ngKAKDtha9sWfIfG42r2CipxSOT4DpddDRP1TIgtl4PUCJyiKYZNSWN4fGsx_kySpD4

McFarland, P., Checinska Sielaff, A., Rasco, B., & Smith, S. (2019). Efficacy of Food Safety Training in Commercial Food Service. *Journal of Food Science*, *84*(6), 1239–1246. https://doi.org/10.1111/1750-3841.14628

Mount, N. J., Chambers, C., Weaver, D., & Priestnall, G. (2009). Learner immersion engagement in the 3D virtual world: principles emerging from the DELVE project. *Innovation in Teaching and Learning in Information and Computer Sciences*, *8*(3), 40–55. https://doi.org/10.11120/ital.2009.08030040

Nguyen, A., Francis, M., Windfeld, E., Lhermie, G., & Kim, K. (2023). Developing an immersive virtual farm simulation for engaging and effective public education about the dairy industry, *118*, Computers & Graphics. https://www.sciencedirect.com/science/article/abs/pii/S0097849323003059

Pribadi, A. P., Rahman, Y. M. R., & Silalahi, C. D. A. B. (2024). Analysis of the effectiveness and user experience of employing virtual reality to enhance the efficacy of occupational safety and health learning for electrical workers and graduate students. *Heliyon*, *10*(15), e34918. https://doi.org/10.1016/j.heliyon.2024.e34918

Santilli, T., Ceccacci, S., Mengoni, M., & Giaconi, C. (2025). Virtual vs. traditional learning in higher education: A systematic review of comparative studies. *Computers & Education*, *227*, 105214. https://doi.org/10.1016/j.compedu.2024.105214

Schütz, A., Kurz, K., & Busch, G. (2022). Virtual farm tours-Virtual reality glasses and tablets are suitable tools to provide insights into pig husbandry. *PLOS ONE*, *17*(1), e0261248. https://doi.org/10.1371/journal.pone.0261248

Spradlin, A., & Saha, S. (2022). Saline aquaponics: A review of challenges, opportunities, components, and system design. *Aquaculture*, *555*, 738173. https://doi.org/10.1016/j.aquaculture.2022.738173

Stefan, H., Mortimer, M., & Horan, B. (2023). Evaluating the effectiveness of virtual reality for safety-relevant training: A systematic review. *Virtual Reality*, *27*(4), 2839–2869. https://doi.org/10.1007/s10055-023-00843-7

Sutherland, C., Sim, C., Gleim, S., & Smyth, S. (2020). Canadian Consumer Insights on Agriculture: Addressing the Knowledge-Gap. *Journal of Agricultural & Food Information*, *21*(1-2), 50–72. https://www.tandfonline.com/doi/full/10.1080/10496505.2020.1724114?casa_token=zvIV8uih-koAAAAA%3AfaMu-xHz6apTq9ybAd3UtYO-4eFh-hOfF9VJjCCjSj55cORu9WoqZh_22dr9ltZzNaNcKpjtLJP2wg

Woon, A. P. N., Mok, W. Q., Chieng, Y. J. S., Zhang, H. M., Ramos, P., Mustadi, H. B., & Lau, Y. (2021). Effectiveness of virtual reality training in improving knowledge among nursing students: A systematic review, meta-analysis and meta-regression. *Nurse Education Today*, *98*, 104655. https://doi.org/10.1016/j.nedt.2020.104655