Computers & Graphics 118 (2024) 173–183

Contents lists available at ScienceDirect

Computers & Graphics

journal homepage: www.elsevier.com/locate/cag

Special Section on RAIXR

Developing an immersive virtual farm simulation for engaging and effective public education about the dairy industry

Anh Nguyen [a,1], Michael Francis [b,1], Emma Windfeld [c], Guillaume Lhermie [c], Kangsoo Kim [b,*]

[a] Department of Computer Science, University of Calgary, 2500 University Drive NW, Calgary, AB T2N 1N4, Canada
[b] Department of Electrical and Software Engineering, University of Calgary, 2500 University Drive NW, Calgary, AB T2N 1N4, Canada
[c] The Simpson Centre, The School of Public Policy, University of Calgary, 906 8 Ave SW, Calgary, AB T2P 1H9, Canada

ARTICLE INFO

Keywords:
Virtual reality
Dairy farm simulation
Public education
Dairy industry
Usability

ABSTRACT

Growing public interest in understanding the origins and production methods of dairy products, driven by concerns related to environmental impact, local sourcing, and ethics, highlights an important trend. Nevertheless, a knowledge-trust gap persists between consumers and the dairy industry. Addressing this gap, in this paper, we developed an immersive virtual farm simulation to provide realistic on-farm experiences to the public. Within the virtual farm, users can explore various sites where dairy cows are raised and gain insights into dairy production processes using a head-mounted display (HMD). This simulation was demonstrated at local libraries, involving 48 public participants. We collected and analyzed participants' feedback on various aspects, including usability and their overall perceptions, to assess the simulation's effectiveness as an agricultural education tool. We investigated the impact of the virtual experience on participants' perceived knowledge gain and their awareness of the dairy industry. The results indicate that our dairy farm simulation was positively received as an effective tool for public education. Emphasizing the potential of virtual reality (VR) simulations in agricultural education and the industry, we discuss our key findings and future plans.

1. Introduction

The public is becoming increasingly interested in investigating the origin of their food and how it is produced, with concerns about environmental impact, local sourcing, and ethics [1–3]. However, the average North American supermarket shopper is detached from how the food they consume is actually produced. The information distributed by the agriculture industry is not effectively reaching the public, and there is a knowledge-trust gap between consumers in Canada and the industry [4]. For example, shoppers are used to seeing the containers of milk and bricks of cheese on the supermarket shelves, but may have never seen a cow or thought about how the livestock that produces these goods are raised on farms outside their city.

Some argue that journalism can influence food consumption behavior [5,6], and social media are becoming increasingly powerful in shaping public opinion based on the viewer's connection to the source [7]. There are also entertainment apps that provide information about the dairy industry. While many 2D farming video games, educational programs, and even some 3D farming VR gaming options are available [8,9], those experiences often only offer a limited sense of how a niche industry or boutique farm operates.

Recently, Virtual Reality (VR) has garnered significant public attention as a promising technology for delivering an accessible and interactive learning experience in the dairy industry, and it has been reported to be an effective educational tool across multiple industries [10–13]. VR has the potential to ensure agriculture information reaches the public in a meaningful way, serving as a supplemental or alternative to conventional media. It can create a strong connection with the public through immersive and interactive virtual experiences that offer verifiable situations for forming opinions [14]. Anastasiou et al. reviewed applications of VR and extended reality (XR) within the agriculture industry and found 55 studies—half of which are educational applications [15]. The study underscores the potential of XR technologies in addressing challenges in the primary sector, emphasizing the need for further research to optimize immersive interactions and overcome health and privacy concerns.

In this paper, we introduce our project where we developed a VR simulation application to provide realistic on-farm experiences to the public. Using the developed application through wearable VR headsets, the public could walk through various sites within a farm where dairy cows are raised. We focus on realizing an interactive,

* Corresponding author.
E-mail addresses: anh.nguyen5@ucalgary.ca (A. Nguyen), mjfranci@ucalgary.ca (M. Francis), emma.windfeld@ucalgary.ca (E. Windfeld), guillaume.lhermie@ucalgary.ca (G. Lhermie), kangsoo.kim@ucalgary.ca (K. Kim).
[1] These authors contributed equally.

https://doi.org/10.1016/j.cag.2023.12.011
Received 31 October 2023; Received in revised form 21 December 2023; Accepted 22 December 2023
Available online 26 December 2023

scientifically accurate on-location experience that teaches the public about agriculture. To accurately depict the context of a real dairy farm, we used contextual appropriate data collected from local dairy farms and informal interviews with farmers and veterinarians. The program was showcased/demonstrated at the Taylor Family Digital Library at the University of Calgary and the Calgary Public Library to examine the potential of the VR experience as a public education tool. During the showcases, we collected subjective questionnaire responses from the public to analyze user experience, learning efficacy, and their thoughts and perceptions about the agricultural production industry.

Through the conducted research, we aim to address the following high-level research questions:

- **RQ1.** Is our virtual dairy farm simulation perceived as a useful medium to educate and inform the public about the dairy industry?
- **RQ2.** How are the user experience and perception metrics correlated to each other in terms of the usability of the system as an educational tool?
- **RQ3.** Does our virtual dairy farm simulation motivate users to learn more about dairy farming and the industry?

The remainder of this paper is structured as follows. Section 2 describes the related work in the scope of agriculture education and virtual farm simulations. Section 3 presents the details of our virtual farm system. Section 4 describes the conducted experiment through public showcases. Section 5 describes our findings, which are discussed in Section 6, and Section 7 concludes our work.

This article is an extended version of the paper presented at the 2nd International Workshop on eXtended Reality for Industrial and Occupational Supports (XRIOS), as a part of the IEEE Conference on Virtual Reality and 3D User Interfaces (IEEE VR) 2023 [16].

2. Related work

This section reviews literature that has examined the relationship between the dairy industry and public education, and the use of VR for educational experiences.

2.1. Public policy and education in dairy industry

While public policy plays a crucial role in shaping the dairy industry through regulations, incentives, and support mechanisms [17], public education holds the potential to shape and impact the policies. To examine how an individual's health beliefs, nutrition knowledge, and attitudes toward food technologies play a role in the anti-consumption of dairy products, Allen et al. conducted an online survey with 1705 Canadian adults [18]. They found that resistance to innovations in food technology, low levels of dairy-specific nutrition knowledge, and the belief that dairy avoidance will not have a negative impact on their health are the main drivers of the anti-consumption of milk and/or yogurt. They found that the same is true for dairy products in general—people who have a higher level of dairy-specific nutrition knowledge are more likely to be anti-consumers of dairy products in general.

In addition, Sutherland et al. found that consumers lack basic knowledge in most areas of agricultural production through a survey of 700 participants from across English-speaking Canada. They recommend that the agriculture industry improves its education and communication efforts with consumers [4]. The self-reported knowledge of the participants tended to be about topics such as organic, certified-humane, hormone-free or genetically modified agriculture, and herbicide use, which are commonly discussed in the media. They raised the concern that the knowledge-trust gap between consumers and Canadian agriculture is a growing issue, despite increased efforts to improve transparency and communication.

While exploring the advantages and disadvantages of different distribution models available to farmers and fishers in Nova Scotia, Canada, Clément et al. published a report that outlined 13 policy-based strategies to enhance community food security and future policy [19]. One of these strategies was to "continue public education awareness on Nova Scotia's food systems and how it can be supported". In a case study, they examined an independent dairy producer, one of only two producer-processors in the province. This producer sells pasteurized, non-homogenized milk—contrary to the dairy production practices of standard farms. The results revealed that the success of this local dairy farm was because "consumers understand that they are receiving a unique, reliable niche product and they keep coming back". The three pillars of the local dairy farm are "to provide service, educate and offer quality product". The dairy farm educates consumers so that they know the type of product they are getting, thus maintaining a loyal customer base.

2.2. Virtual experience for education

VR has been shown to be a functional tool for education due to the immersive and interactive experience that users have [20–22]. In 2000, Allison and Hodges developed a VR system to explore how the technology might be used to aid in educating middle school students for knowledge acquisition and concept formation [23]. They built a testbed VR system to teach student participants about Gorillas, and their results showed that the system had the potential as a public education tool. Through the study, they realized that there were not enough resources to generate worthwhile content, but were optimistic that once content generation and suitable hardware became economically viable there would be great utility for VR in public education.

In 2012, Tarng et al. developed a web-based virtual farm application to study its effects on education [24]. 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 grade 3 students' learning effectiveness and motivation.

Recently, in 2022, Lampropoulos et al. studied the public's perspectives, sentiments, attitudes, and discourses regarding the adoption, integration, and use of Augmented Reality (AR) and VR in education [25]. They collected and analyzed 17 million Twitter posts from January 2010 to December 2020, creating four datasets—two referred to the general use of VR and AR, and the other two referred to their educational use. They found that the majority of the public was positively inclined towards the general and educational use of AR and VR.

2.3. Virtual reality for agricultural education

Regarding the role of VR in agriculture education, there are articles that discuss the potential of VR for training [26] and study the implementation of VR for training [27,28]. Yu et al. introduced the idea and discussed the potential of VR to improve the efficiency of agriculture production [26]. Ye et al. also studied the use of VR to address poor spatial thinking ability and weak hands-on operation ability for Tibetan-Chinese students in pastoral areas [27]. Urem et al. discussed the use of VR to develop competencies and skills for young people who want to develop their agribusiness [29].

To aid in the evaluation of e-learning and VR applications for agriculture, Jimenez et al. identified the most commonly used variables for measuring the technology acceptance [28]. Their analysis showed that computer self-efficacy, individual innovativeness, computer anxiety, perceived enjoyment, social norms, content and system quality, self-experience, and facilitating conditions are the most common variables that determine technology acceptance. They found that a system's perceived usefulness was determined primarily by its perceived ease of use, followed by content quality and perceived enjoyment, and the perceived ease of use was significantly influenced by self-efficacy, perceived enjoyment, and self-experience.

To improve transparency in husbandry conditions and animal welfare, Schütz et al. developed a virtual tour of a conventional pig farm, showing study participants a 360-degree video on both a tablet and VR headset [30]. They conducted interviews after the experience to analyze the perceptions of participants and the differences between the media devices. The results showed that participants described virtual farm tours as a suitable tool to improve transparency and knowledge transfer and to gain insight into animal conditions. They favored the tablet for its usability and the VR headset for its realism and entertainment value, but said that both devices were entertaining, which would likely enhance their interest in engaging with the topic. However, their simulation content was only video-based, not 3D virtual models, and they did not involve any interactive virtual avatars or agents. They claimed that the video sequences shown without additional explanation were insufficient to help them understand the content. In our work, we develop a 3D virtual farm environment with interactive virtual characters and other context-relevant virtual models, such as animated virtual cows, wagon, and milk tank, to see the effects of the virtual simulation in the user's perception and learning experience.

3. Virtual dairy farm simulation

In this section, we describe the details of how we designed and developed our virtual dairy farm simulation.

3.1. Data collection for virtual dairy farm design

To design an accurate and realistic dairy farm simulation, we consulted with both international researchers and local farmers. For instance, we had an online meeting with Dr. Maxime Delsart (Veterinary Medicine, École Nationale Vétérinaire d'Alfort) to learn from his experience in developing a 360-degree video-based immersive farm simulation [31]. The video experience that they developed was an educational tool for veterinary students to learn about biosecurity rules on pig farms. Dr. Delsart provided a detailed description of the interactive educational program including the interface options, content creation, farmer narration, safety procedure, etc., which helped us design our dairy farm simulation.

While collecting video/image footage on the web, we also visited local dairy farms to collect photos, videos, and information about farm operations in Alberta, Canada[2] (see Fig. 1). An extensive collection of videos and photos captured the barn's layout, serving as a reference to design a virtual environment that accurately portrays the real barn.

To ensure the authenticity and precision of our system, we closely followed farmers and asked them questions to gain a thorough understanding of dairy farm operations. This offered valuable insights that aided us in the design of our virtual dairy farm. For example, the barn itself is divided into several spaces. An indoor area provides a resting and feeding space for older calves and non-milking cows. Milking cows occupy a cooler section where they can voluntarily enter the rotary parlor for milking. Mother cows and their newborns are segregated from the rest of the population in their own space. An insightful revelation emerged from our conversations with the farmers that cows tend to remain quiet unless they are unwell. This led us to omit cow sounds from the background noise in our virtual simulation.

To respond to the public's concern regarding antibiotic usage on dairy farms, we also conducted a meticulous investigation. We scrutinized video documentation of the milking procedure on the farm and engaged in conversations with farmers to acquire a comprehensive perspective. We found that sick cows are administered antibiotics as

[2] Breakfast on the Dairy Farm (2022): https://www.familyfuncanada.com/calgary/breakfast-dairy-farm/ (Accessed 2023-01-21).

(a) Feeding area where cows rest and eat.

(b) A food mixer wagon.

Fig. 1. Photos captured during the local farm visits.

per veterinarian prescriptions, and their milk is excluded from production. Additionally, any milk dispatched from a cow within a specified timeframe after its illness is promptly discarded. We also consulted with nutritionists, who provided us with insights about the dietary menu of cows on farms in Alberta. The knowledge we acquired during our farm visits was integrated into our simulation to be communicated to the user.

3.2. Farm layout and experience design

Inspired by our firsthand experience of actual farm visits, we chose to model the farm environment as a continuous indoor space. Reflecting the common practice of segmenting farms into distinct sections for various groups of cows, we divided the virtual farm into five primary areas: (1) cross-section, (2) feeding, (3) veterinary, (4) calving, and (5) milking (see Fig. 2).

In the experience, VR users first find themselves in the cross-section area, allowing them to explore the barn environment freely. However, movement is confined to the indoor barn space. The detail of each area is described below.

Cross-section area. The cross-section area, where users start their virtual farm experience, connects the other four areas on the barn's left and right sides (Fig. 2). Here, information panels and videos are affixed to the walls, allowing the users to read or view materials that provide a deeper understanding of cow nutrition and animal welfare (Fig. 3(a)). The videos were contributed by experts in animal welfare and agriculture research, including veterinarians, nutritionists, scholars, and farmers. There is also a virtual nutritionist describing her role in the farm. An example of the nutritionist's speech is below.

> *"Nutritionists work together with dairy farmers to plan each cow's diet to optimize health through nutrition based on her age and stage of lactation and then customize rations or recipes to specific forages grown on farm. Milking or lactating cows eat a different ration from cows..."*

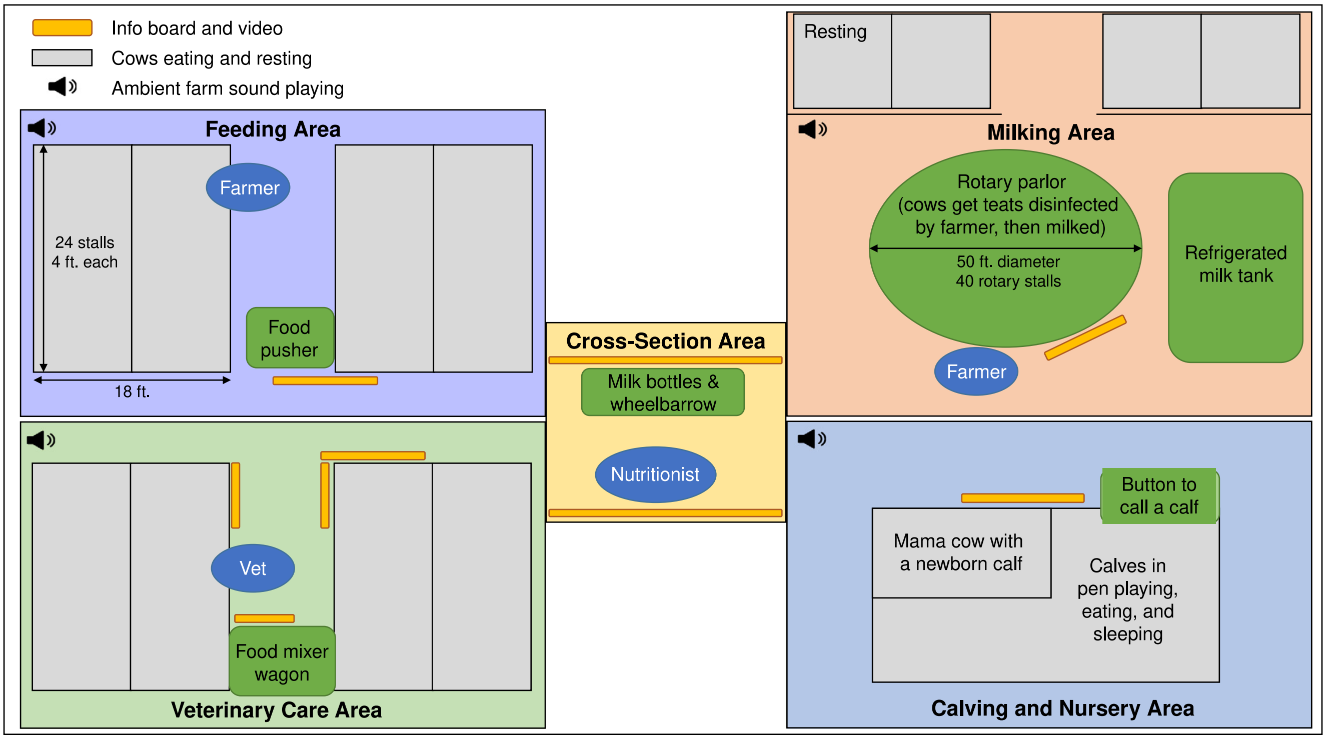

Fig. 2. A layout of our virtual farm design, which consists of five areas: feeding, milking, veterinary, calving, and cross-section areas.

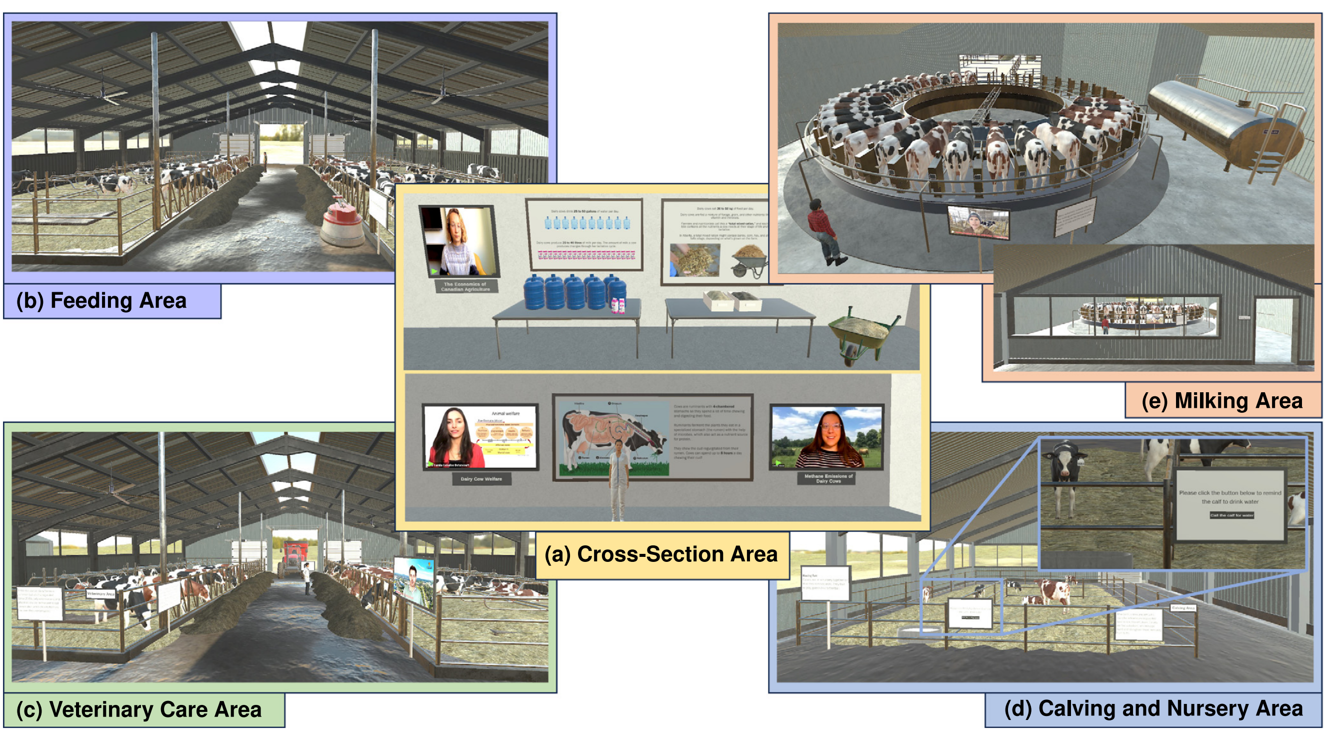

Fig. 3. Sample scenes captured in the virtual dairy farm simulation: (a) the cross-section area where a virtual nutritionist and experts' videos explain the cow nutrition and animal welfare, (b) the feeding area with a virtual farm and the food pusher, (c) the veterinary care area with a vet, a food wagon, and an expert video, (d) the calving area where the user can interact with one of the calves, and (e) the milking area with another farmer.

Feeding area. The feeding area is situated on the left side of the barn (Fig. 3(b)). The area features 24 stalls on both sides, providing a space for non-milking cows to eat and rest. Along the stall fences, there are mixtures of grasses that cows consume. Access to cow stalls is restricted, akin to an in-person farm visit experience. In the feeding area, users can also observe a food pusher mechanism designed to move food toward cows, as they tend to push it away while eating. This automated device, commonly used on modern dairy farms, is showcased for observation. Information detailing the functions of the food pusher is provided via a text panel in front of the feeding area. Furthermore, within the feeding

Fig. 4. Virtual agents: a nutritionist, a veterinarian, and two farmers (from left to right).

area, users have the opportunity to engage with a virtual farmer who discusses the topic of antibiotic usage on dairy farms (see Fig. 4). An example of the farmer's speech is below.

> *"This cow has mastitis – it's an udder infection. We try to avoid using antibiotics too often, but for infections like this, she's in a lot of pain and she can't produce good quality milk. I'm giving her antibiotics for 3 days; that'll clear up the infection. During the days she's on antibiotics..."*

Veterinary area. The veterinary area is located on the left side of the barn, right next to the feeding area. It has a similar structure of stalls and houses a number of non-milking cows. The area has a food mixer wagon, which is utilized to blend all dietary components for cows and distribute the mixture among the stalls (Fig. 3(c)). The details of the dietary information and the use of the mixer wagon are provided via adjacent text panels. Complementary to these descriptive displays, various text panels are dispersed throughout the barn, offering supplementary explanations regarding dairy products and cow care. In the area, a virtual veterinarian stands beside a cow, elaborating on her role in the dairy farming context (Fig. 4). The script and audio recording for the veterinarian agent were composed in consultation with certified veterinarians.

> *"As a veterinarian, I work with farmers to create a vaccination program that prevents their cows from getting common diseases. Every farm is required to have its own vaccination program under the rules of proAction, which is a national quality assurance program for the Canadian dairy sector..."*

Calving area. Moving from the cross-section, participants arrive at the calving and nursery area, designated for mother cows and their newborns. There are three young calves that have been separated from their mothers. When users approach a fence, an interactive button interface appears so that they can engage with the calves by activating the button that attracts a calf closer to the fence for drinking water (see Fig. 3(d)).

Milking area. The milking area includes two subsections: the cows' resting area and the rotary parlour. While users are unable to enter the area where milking cows rest, they can access the rotary parlour section. They can observe cows within a rotating parlour, preparing for milking. The presence of pipes and cooling tanks in the room illustrates the path taken by collected milk to reach the outside silos. While a virtual farmer standing by the parlour explains the milking process, a video panel also introduces technologies employed in dairy farming (Fig. 3(e)). An example of the virtual farmer's speech is below.

> *"First, the cow walks up into the rotary parlour. I clean her udder with a cloth and disinfectant to make sure everything is sanitary and clean, then attach the milking units to her teats. After the cow is done milking – which takes about 5 or 10 min – she leaves the rotary parlour and goes back to the barn..."*

3.3. Virtual dairy farm development

Following the virtual farm design described in the previous section, we developed our virtual dairy farm simulation in an immersive virtual environment. Design is an iterative process [32–34], and in order to capture the correct and realistic representation of the real dairy farm and industry, we iterated upon a series of prototype testing and ground-truth discovery with farmers, veterinarians, dairy industry representatives, and animal welfare experts. To ensure accuracy, we shared a video walkthrough of the virtual environment with a local farmer for their evaluation, and adjusted the simulation based on their feedback, such as the depiction of cows' sleeping positions—cows typically favor one side while sleeping. Our commitment to accuracy also extended to the animals' care. We were rigorous to seek insight from veterinarians, industry representatives, and animal welfare experts to refine our system's portrayal of care. After exhaustive validation, our final virtual dairy farm simulation was formally launched for public showcases and user research.

We used commercial off-the-shelf virtual models for the cows, but we also hired a graphic designer to create 3D models and animation schemes to improve the realism of the experience. In addition, we included recurrent background sounds recorded on a real farm to enhance the realism. Unity Gaming Engine (version 2021.3.1f1) was used to create the simulation, and we used the OpenXR plugin (version 1.3.1) to ensure that the simulation was compatible with multiple VR headsets for scalability. The final application was deployed on an Oculus Quest 2.

For users to interact with the virtual environment, we allowed them to use only the right-hand controller to streamline their experience. We used the XR Interaction Toolkit[3] for camera control, which allows the user to rotate and teleport around the virtual space. To initiate teleportation, users aim the controller toward the ground, directing the emitted ray to their desired destination. While there is no limited distance for traveling, access to certain parts of the virtual space is restricted to avoid collisions between the user and the various models we implemented. The color of the ray serves as an indicator of the target location's accessibility. For instance, the ray turns from white to red when teleportation is not possible. As long as the ray remains white, users should be able to teleport. To activate teleportation, users simply press the index trigger on the controller, instantly relocating them to the designated location. Snap turning is supported by tilting the thumbstick in the preferred direction, effecting an immediate 45-degree pivot.

We employed lifelike virtual human models and animations to enhance the overall realism of the immersive experience. We used Microsoft Rocketbox library [35], which came with various virtual human models and animation clips (see Fig. 4). Additionally, we recorded human voices for character audio and utilized Salsa LipSync Suite[4] to make realistic lip-sync. For the interaction of calling a calf in the calving area, collision detection at the fences will trigger a calf to walk toward the user for an immersive experience.

4. Experiment

We showcased the developed virtual farm simulation system at local libraries and conducted a user study with the visitors to evaluate the effectiveness of the developed virtual farm simulation as a tool for public agriculture education.

[3] Unity XR Interaction Toolkit: https://docs.unity3d.com/Packages/com.unity.xr.interaction.toolkit@2.2/manual/index.html (Accessed 2023-01-21).

[4] Salsa LipSync Suite: https://crazyminnowstudio.com/docs/salsa-lip-sync/ (Accessed 2023-01-21).

Fig. 5. An image capturing a participant immersed in the virtual barn environment.

4.1. Participants

To validate the potential of our virtual farm simulation for public education about the dairy production industry, "VR Dairy Farm" exhibitions were open to the public in the Taylor Family Digital Library and the Calgary Public Library in November 2022.[5] All participants were visitors to the two libraries, who were interested in the experience. The study was approved by the University of Calgary Human Research Ethics Board (REB22-0819).

59 people participated in the study. However, we excluded 11 participants due to incomplete responses. Consequently, the data analyzed in this work is derived from 48 (26 male, 19 female) out of the initial 59 participants, whose ages ranged from 17 to 60 years, with an average age (M) of 32.3 years and a standard deviation (SD) of 11.16 years. Among these participants, 21 individuals reported no prior experience with VR devices. Additionally, 47 participants disclosed that they regularly consume dairy products, with 9 of them indicating that they restrict their dairy consumption due to various concerns, including but not limited to animal welfare, personal health, and environmental considerations. In terms of their previous farm experience, 29 have visited but not worked on a farm, 10 have never visited or worked on a farm, and 9 have worked on a farm. Also, the average score on their self-reported dairy farm/industry knowledge was 2.04 (SD: 1.05), which is at the level of "slightly knowledgeable" on a 5-point scale (1. Not knowledgeable at all – 5. Extremely knowledgeable).

4.2. Settings - apparatus and study space

We used the Oculus Quest 2 headset for this study. Since all interactions and movements can be done using the right controller, the participants only held the controller in their right hand. The first set of exhibitions took place in the Taylor Family Digital Library on the university campus. The exhibition space was located in a dedicated closed room specifically designed for the development and testing of VR projects. People who frequented the library could spot posters on the walls, which drew their attention and led them to visit the room to go through the experience. The library staff were on hand to provide assistance.

The second set of exhibitions took place in an open area within the Calgary Public Library (see Fig. 5). We strategically positioned posters at the library's entrance to attract visitors. Anyone intrigued by the VR experience could easily access the designated area near the entrance. Additionally, we set up a table where visitors could peruse the study-related documentation.

To ensure the smooth operation of the showcase and assist members of the public to engage in the virtual farm experience, we hired students who acted as facilitators and monitors. These facilitators helped participants adjust their headsets for optimal visibility of the virtual scene and instructed them in the proper use of the right-hand controller. To mitigate the risk of cybersickness and physical injury, participants were instructed to remain seated on swivel chairs throughout the experience.

4.3. Procedure

The participants were given information sheets in advance that informed them about the simulation and the potential risks that accompany the use of VR devices. After a facilitator assisted them in wearing the headset, participants were recommended to go through the optional tutorial, which is described below as an instruction scene, before exploring the virtual farm. After completing all the tasks in the tutorial, they were introduced to the barn scene, which we described in Section 3. Participants could freely explore the barn for as long as they wanted. After completing the experience, they had the option to voluntarily complete questionnaires.

Instructional scene. Because this project engaged a diverse public audience spanning several demographics, participants may lack familiarity with VR technology or require time to learn new technical concepts. Consequently, we developed an instructional scene to guide participants in how to use the system before immersing themselves in the virtual farm environment. Those who opted for the tutorial were introduced to a virtual room where they followed step-by-step instructions to complete various tasks instrumental to interacting with our system. Participants learned to interact with the user interface and virtual human agents, and how to utilize teleportation to navigate. Once all tutorial tasks were accomplished, they gained access to the primary scene, the expansive farm setting.

4.4. Measures

To assess the usability of our virtual farm simulation and gather participants' perceptions of the virtual experience, we administered a questionnaire that included standardized questions as well as custom ones on a 5-point Likert scale (1: Strongly Disagree, 5: Strongly Agree).

Usability. The usability of the system indicates if the system is effective and easy to use. The System Usability Scale (SUS) [36] was used to evaluate the usability of our developed virtual farm simulation. The SUS has been widely used to assess systems. This scale, consisting of ten questions, serves as a valuable metric for evaluating the effectiveness and user-friendliness of a system. By collecting user ratings and applying a specific calculation method, we can derive a system's SUS score. To calculate this score, each participant's ratings for the individual questions are summed, and the total is then multiplied by 2.5. This transformation converts the original scores, which range from 0 to 40, into a more intuitive 0–100 scale—typically, a SUS score of 68 is considered average [37].

Trustworthiness. We aimed to provide accurate information about the dairy industry and local dairy farms through the developed virtual farm simulation. To assess the participant's perception of the authenticity of the provided information in the simulation, we prepared a question: *"The things I saw in the VR experience seemed trustworthy and unbiased"*.

Knowledge Gain. To evaluate whether our virtual farm simulation could give the participants an opportunity to learn about the dairy farm and industry or not, we also measured the participant-perceived knowledge acquisition using a question: *"I learned new things from the VR experience"*.

[5] Experience a Dairy Farm in Virtual Reality: https://www.simpsoncentre.ca/events/VRdairyfarm/ (Accessed 2023-01-21).

Table 1
Usability and perception score statistics.

Variable (Range)	Median	Mean	Std. Deviation
Usability (0–100)	60.00	63.91	16.64
Trustworthiness (1–5)	4.00	3.65	1.18
Knowledge Gain (1–5)	4.00	3.92	1.09
Education Fit (1–5)	4.00	4.33	0.69
Dairy Awareness (1–5)	4.00	3.88	0.91
Recommendation (1–5)	4.00	4.38	0.70

Education Fit. To assess the potential of our virtual farm simulation as a useful tool for public education, we included a question: *"This VR experience is a useful platform for public agricultural education".*

Dairy Awareness. Our virtual farm simulation aims to enhance participants' awareness and understanding of the dairy industry. To measure the impact of the virtual experience on their dairy awareness, we included a question: *"This VR experience helped me understand the overall dairy farm environment and food production".*

Recommendation. As an indirect measure of the perceived value of our virtual farm experience, we asked participants for their willingness to recommend it to other people using a question: *"I would recommend this VR experience to my friends and family".*

Level of Interest. To assess the participant's level of interest in dairy farming before and after the virtual farm experience, we included two questions: *"What was your level of interest in dairy farming before this VR experience?"* and *"What is your level of interest in dairy farming now?"* (1: Not interested, 5: Very interested).

Word Choice. Additionally, we asked a word-choice question, *"What words describe your VR experience?"* where multiple options were available: (positive words) educational, fun, exciting, easy to navigate; (negative words) difficult to navigate, confusing, glitchy, challenging.

5. Results

Both descriptive and inferential statistical analyses were conducted on the measurements collected from 48 participants. We began by presenting descriptive statistics, such as means and standard deviations, for all measurements to assess the overall user evaluations of the virtual farm simulation. Additionally, we explored potential relationships and patterns in the data by examining the correlations among the measurements. We then conducted a non-parametric statistical analysis (a paired Wilcoxon signed rank test) to determine if there were any significant differences in user evaluations, specifically on the level of interest in dairy farm/industry in terms of the timing of evaluations (i.e., before and after the virtual farm experience). These analyses collectively provide a comprehensive understanding of user perceptions, enabling us to draw meaningful conclusions about the virtual farm simulation's user experience. The significance level was set at 5%.

5.1. Overall descriptive statistics

To capture the overall scores on the usability and perception measures: trustworthiness, knowledge gain, education fit, dairy awareness, and recommendation, which we describe in Section 4.4, we present the descriptive stats of all these measures (see Table 1). For more details, we also report the histograms of all these measures to show the participant distributions in the scales (see Fig. 6).

The reported usability score of our virtual farm simulation was a bit lower than the common average score (M = 63.91 out of 100, SD = 16.64). However, for all other measures, the participants perceived that the virtual farm experience was positive and useful. In general, they thought that the provided information was trustworthy (M = 3.65, SD = 1.18), they learned new things (M = 3.92, SD = 1.09), the simulation was a useful education tool (M = 4.33, SD = 0.69), the virtual experience improved their dairy farm awareness (M = 3.88, SD = 0.91), and they would recommend this experience to their acquaintances (M = 4.39, SD = 0.70).

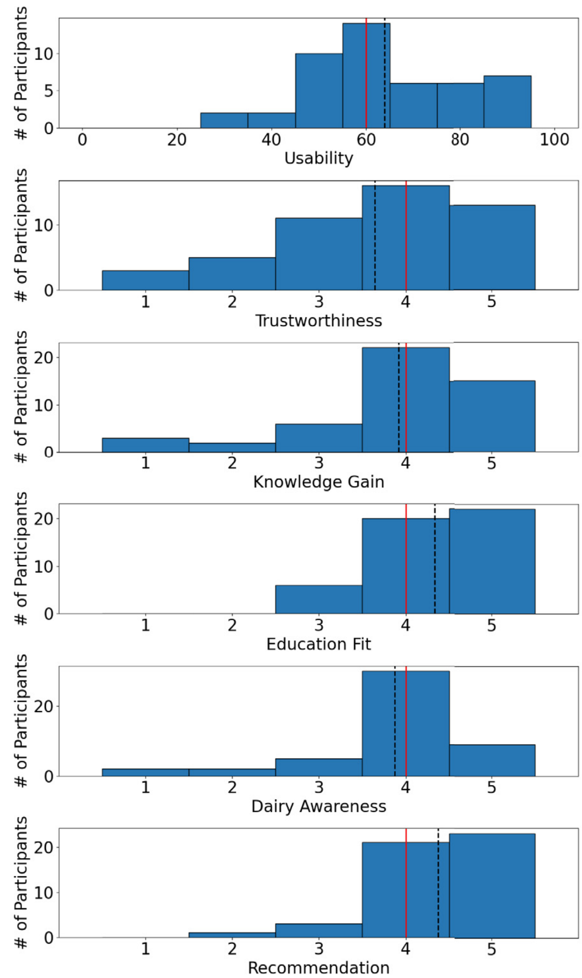

Fig. 6. Histograms for the measures: usability, trustworthiness, knowledge gain, education fit, dairy awareness, and recommendation. Red line is median. Dashed line is mean.

5.2. Correlations

We conducted Pearson's correlation tests to analyze the relationships among the measures. Our findings revealed weak to moderate correlations between some of the measures, and these correlations were statistically significant. The details of the correlations are shown in Table 2, and for those with statistical significance, we draw the detailed distributions and lines of best fit to visualize the correlations in Fig. 7.

Education Fit was positively associated with several measures: a weak correlation with Usability ($r(46)$ = .341, p = .018), a weak correlation with Knowledge Gain ($r(46)$ = .319, p = .027), and a moderate correlation with Recommendation ($r(46)$ = .479, p < .001). This means that the increase in Education Fit was correlated with the increases in the other measures.

Similarly, Dairy Awareness also had positive correlations with several other measures: a weak correlation with Education Fit ($r(46)$ = .335, p = .020), a moderate correlation with Knowledge Gain ($r(46)$ = .460, p = .001), and a moderate correlation with Trustworthiness ($r(46)$ = .413, p = .003). Again, this indicates that the increase in Dairy Awareness was correlated with the increases in the other measures listed above.

Table 2
Pearson's correlation coefficients among the measures and the statistical significances.

Variable		Usability	Trustworthiness	Knowledge Gain	Education Fit	Dairy Awareness	Recommendation
Usability	Pearson's r	–					
	p-value	–					
Trustworthiness	Pearson's r	−0.129	–				
	p-value	0.382	–				
Knowledge Gain	Pearson's r	0.203	0.259	–			
	p-value	0.166	0.075	–			
Education Fit	Pearson's r	0.341	0.122	0.319	–		
	p-value	**0.018***	0.410	**0.027***	–		
Dairy Awareness	Pearson's r	0.110	0.413	0.460	0.335	–	
	p-value	0.458	**0.003****	**0.001****	**0.020***	–	
Recommendation	Pearson's r	0.327	0.113	0.320	0.479	0.108	–
	p-value	**0.023***	0.446	**0.027***	< **.001*****	0.467	–

* $p < .05$, ** $p < .01$, *** $p < .001$.

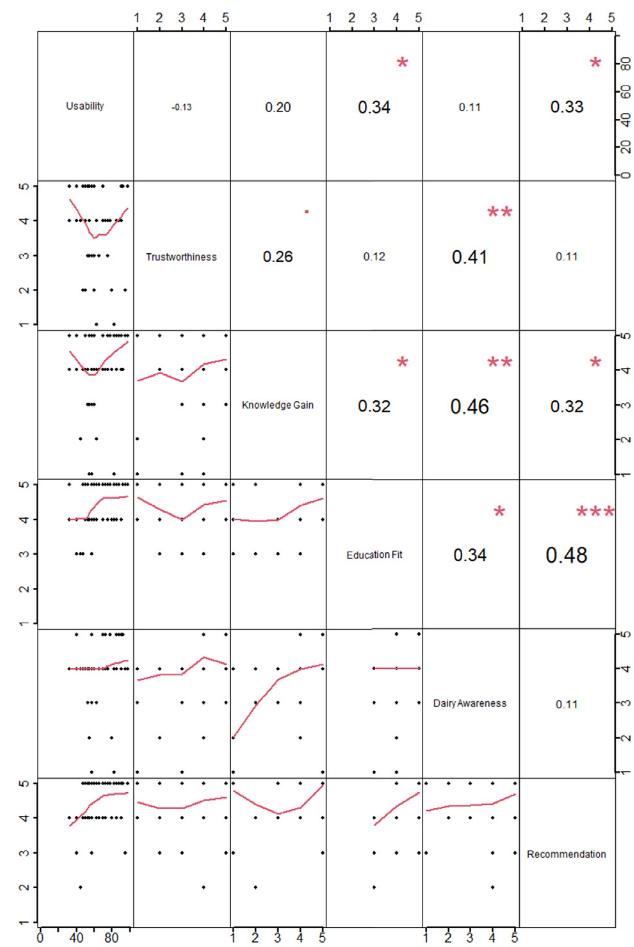

Fig. 7. Correlations among the measures with statistical significances (* $p < .05$, ** $p < .01$, *** $p < .001$). Multiple points are replicated at the same location in the figures.

Recommendation (participant's willingness to recommend this experience to others) was also weakly associated with Usability ($r(46) = .327$, $p = .023$), and Knowledge Gain ($r(46) = .320$, $p = .027$). This shows that the increase in Recommendation was also correlated with the increases in Usability and Knowledge Gain.

5.3. Level of interest in dairy farming

To understand how the virtual farm experience could influence the participant's level of interest in dairy farming, we used a paired Wilcoxon signed-rank test on the Level of Interest. The result shows an

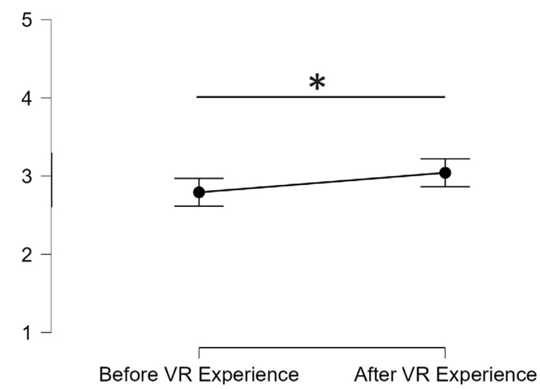

Fig. 8. The increased Level of Interest in dairy farming after the VR experience. The accompanying means and standard error bars are displayed.

increase in the participant's interest in dairy farming after the virtual experience ($M = 3.042$, $SD = 1.071$) compared to the interest level before the experience ($M = 2.792$, $SD = 1.304$); $Z = -1.773$, $p = 0.033$ (see Fig. 8). This indicates that our virtual farm simulation could encourage the participants to learn more about dairy farming and the industry.

5.4. Word choice

Regarding the word-choice question, "What words describe your VR experience?", a majority of the participants positively reported that the experience was educational ($N = 31$), fun ($N = 28$), and exciting ($N = 25$) (see Fig. 9). Although there were some participants reported that the navigation mechanism was a bit difficult, the number of participants who chose negative words, i.e., confusing, challenging, glitchy, was fewer than 10. This indicates that the developed virtual farm simulation was perceived as a fun, exciting, and effective learning tool for public education about dairy production.

6. Discussion

6.1. Key findings

In this research, we aimed to address three high-level research questions introduced in Section 1. Regarding those questions, first, we wanted to study whether our virtual farm simulation could be perceived as an effective public education tool or not. Based on the results that we extracted from our study participants' responses, the developed virtual farm experience was perceived positively in general. Although the usability score of our system ($M = 63.91$) did not fall exactly within the satisfactory range according to Sauro [37], the scores on other perception measures including Education Fit, Knowledge Gain, and Recommendation were high. The relatively low usability score could be

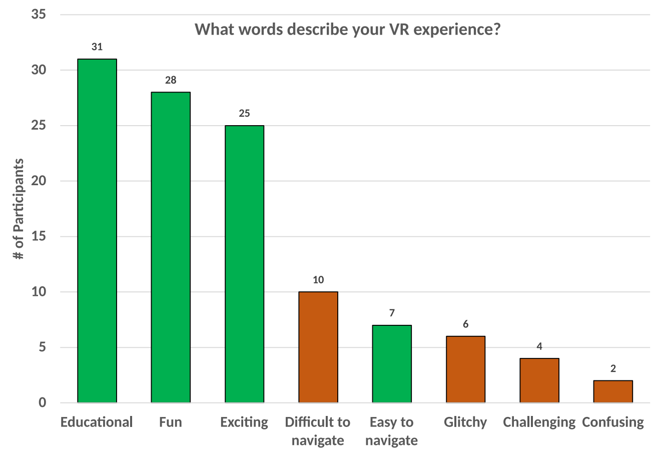

Fig. 9. Results of the participants' responses for a question, "What words describe your VR experience?" The number of participants who selected the word is shown. Green and orange bars are positive and negative words, respectively.

explained by the discomfort in the navigation mechanism as the participants reported in the word-choice question—ten participants chose "difficult to navigate" using the VR controller in the immersive virtual farm environment. The positive assessment of our farm simulation as an education tool could also be supported by the positive words that the participants selected, e.g., educational, fun, and exciting, describing the virtual experience, as well as the high score in other measures, such as the perceived knowledge gain.

Second, we conducted a correlation analysis to explore the relationships between various measures that we have in the study, and found several significant correlations between some of them. Positive correlations were found between the perception of Education Fit and Usability, Knowledge Gain, Dairy Awareness, and Recommendation. This suggests that participants who viewed the system favorably in terms of its educational suitability also tended to rate the system higher in terms of usability, reported increased knowledge gain, demonstrated heightened awareness of the dairy industry, and were more likely to recommend the system. However, it is important to note that correlation does not imply causation, and these findings only highlight the statistical associations observed in our study. Additionally, individuals' personal perspectives on how food production looks and the disparity may impact their perception of the content quality, which we may need to consider in understanding the meaning of the results.

Third, we wanted to investigate the effect of a virtual dairy farm simulation on user's motivation to learn about the dairy farming industry. We found that there was a significant increase in participant's interest after using our system. Overall, participants rated the experience as educational and entertaining based on the positive words that they selected to describe our virtual farm experience. This is in line with the work of Schütz et al. which addressed that a VR experience is favored for its realism and entertainment value, compared to a tablet application [30]. Also, they perceived that they could learn about the dairy farm/industry from the virtual experience, i.e., the high score in Knowledge Gain, and expressed their willingness to recommend the system to their friends and family. The correlations we found between Dairy Awareness and Knowledge Gain could also be related to this learning motivation—e.g., as people learn, they want to learn more.

6.2. Limitations and future work

While our virtual farm simulation generally received positive feedback, we have also identified certain limitations that will guide our future work. As addressed above, there were several negative impressions about the virtual farm experience, e.g., difficult to navigate, glitchy, challenging, and confusing. We did not particularly focus on the perceived cybersickness [38] during the experience in our study, but the difficulty and glitches during the navigation may have caused an unpleasant sense of motion sickness or discomfort while using an immersive head-mounted display (HMD), which could impact the usability score. Also, as VR, especially immersive HMDs, is still not a common household technology, the participants may not be familiar with the use of these novel devices [39]. As the pervasiveness of the technology grows, or as the technological literacy of society improves [40], this may resolve itself, but further development in our case can work to improve the user experience.

Also, the current study was conducted effectively in an in-the-wild setting with random participants in public libraries; however, it did not involve any other mobile or desktop systems for formal comparisons. Comparative studies can be conducted to evaluate the effectiveness of VR-based education compared to other conventional methods, such as social media campaigns or school curriculum integration. For example, Schütz et al. revealed that the usability of VR was rated lower than the tablet [30]. Our results show that our participants reported slightly below-average usability as well; however, further investigation in a formal comparative study is required. Additionally, the libraries serving as our exhibition sites may attract a public with a specific interest in literacy. We should note that this could introduce a potential bias in the research focused on dairy farms and industry education.

In addition, future studies can further investigate the long-term impact of the VR experience on consumer behavior and the potential for widespread adoption of VR-based agricultural education initiatives [41]. The research can also explore ways to enhance collaboration between the agriculture industry, educators, and technology developers to create more comprehensive and informative VR experiences for the public [42].

7. Conclusions

It is important to bring accurate information about agricultural production to consumers so that they can understand how farmers produce the food they eat and so they can develop trust in the industry. Bringing transparency to the agri-food system through immersive VR experiences can build public trust in food and farmers, address hesitation or misunderstanding about production practices, such as the use of new technologies, and help consumers make more informed choices at the grocery store.

In this paper, we presented an immersive VR-based dairy farm simulation for public users (e.g., dairy product consumers) to experience and learn about how dairy products are produced in healthy farm environments. The results of our showcases involving study participants showed that the developed system was perceived as an effective and useful learning tool to provide authentic information to consumers, while also encouraging them to learn more about the dairy farm and industry.

This project will continue extending the features of the VR experience, e.g., more interactive activities with virtual entities in the simulation for better learning outcomes and motivation. For example, in the updated version, users should be able to have a first-hand experience interacting with virtual processes on the dairy farm, such as milking the cow and operating the milking machine. We will also develop a multi-user communication feature to connect farmers and consumers in the shared virtual space. We plan to create different virtual simulations beyond the scope of dairy production, to cover various types of agri-food industry, e.g., pork, poultry, and aquaculture.

CRediT authorship contribution statement

Anh Nguyen: Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Visualization, Writing – original draft, Writing – review & editing. **Michael Francis:** Data curation, Formal analysis, Investigation, Writing – original draft, Writing – review &

editing. **Emma Windfeld:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing. **Guillaume Lhermie:** Conceptualization, Funding acquisition, Investigation, Project administration, Supervision, Writing – review & editing. **Kangsoo Kim:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

Acknowledgments

This work was supported by grants from the Simpson Centre, the School of Public Policy, and the Schulich School of Engineering Undergraduate Student Research Award at the University of Calgary, Canada. We acknowledge the support of the Natural Sciences and Engineering Research Council of Canada (NSERC), [RGPIN-2022-03294]. The authors wish to thank Dr. Maxime Delsart (Veterinary Medicine, École Nationale Vétérinaire d'Alfort), Tietsia Huyzer (Huntcliff Dairy Ltd., Olds, AB), and other domain experts for sharing their knowledge and experience. We also thank our graphic designer, Harry Cho, for his contribution to designing the 3D models and animations.

References

[1] Weatherell C, Tregear A, Allinson J. In search of the concerned consumer: UK public perceptions of food, farming and buying local. J Rural Stud 2003;19(2):233–44. http://dx.doi.org/10.1016/S0743-0167(02)00083-9.

[2] Arenna, Goddard E, Muringai V. Consumer purchase intentions for pork with enhanced carnosine–A functional food. Can J Agric Econ 2019;67(2):151–69. http://dx.doi.org/10.1111/cjag.12190.

[3] Muringai V, Fan X, Goddard E. Canadian consumer acceptance of gene-edited versus genetically modified potatoes: A choice experiment approach. Can J Agric Econ/Rev Can d'agroecon 2020;68(1):47–63. http://dx.doi.org/10.1111/cjag.12221.

[4] Sutherland C, Sim C, Gleim S, Smyth S. Canadian consumer insights on agriculture: Addressing the knowledge-gap. J Agric Food Inf 2020;50–72. http://dx.doi.org/10.1080/10496505.2020.1724114.

[5] Happer C, Wellesley L. Meat consumption, behaviour and the media environment: a focus group analysis across four countries. Food Secur 2019;11(1):123–39. http://dx.doi.org/10.1007/s12571-018-0877-1.

[6] Pabian S, Hudders L, Poels K, Stoffelen F, De Backer C. Ninety minutes to reduce one's intention to eat meat: A preliminary experimental investigation on the effect of watching the cowspiracy documentary on intention to reduce meat consumption. Front Commun 2020. http://dx.doi.org/10.3389/fcomm.2020.00069.

[7] Turcotte J, York C, Irving J, Scholl RM, Pingree RJ. News recommendations from social media opinion leaders: Effects on media trust and information seeking. J Comput-Mediat Commun 2015;20:520–35. http://dx.doi.org/10.1111/jcc4.12127.

[8] Calsamiglia S, Espinosa G, Vera G, Ferret A, Castillejos L. A virtual dairy herd as a tool to teach dairy production and management. J Dairy Sci 2020;103(3):2896–905. http://dx.doi.org/10.3168/jds.2019-16714.

[9] Chang AY. Back to the virtual farm: Gleaning the agriculture-management game. Interdiscip Stud Lit Environ 2012;19(2):237–52.

[10] Bricken M. Virtual reality learning environments: Potentials and challenges. ACM SIGGRAPH Comput Graph 1991;25(3):178–84. http://dx.doi.org/10.1145/126640.126657.

[11] Özacar K, Ortakcı Y, Küçükkara MY. VRArchEducation: Redesigning building survey process in architectural education using collaborative virtual reality. Comput Graph 2023;113:1–9. http://dx.doi.org/10.1016/j.cag.2023.04.008.

[12] Han B, Weeks DJ, Leite F. Virtual reality-facilitated engineering education: A case study on sustainable systems knowledge. Comput Appl Eng Educ 2023;31(5):1174–89. http://dx.doi.org/10.1002/cae.22632.

[13] Awori J, Friedman SD, Howard C, Kronmal R, Buddhe S. Comparative effectiveness of virtual reality (VR) vs 3D printed models of congenital heart disease in resident and nurse practitioner educational experience. 3D Print Med 2023;9(1). http://dx.doi.org/10.1186/s41205-022-00164-6.

[14] Wu H, Cai T, Luo D, Liu Y, Zhang Z. Immersive virtual reality news: A study of user experience and media effects. Int J Hum-Comput Stud 2021;147:102576. http://dx.doi.org/10.1016/j.ijhcs.2020.102576.

[15] Anastasiou E, Balafoutis AT, Fountas S. Applications of extended reality (XR) in agriculture, livestock farming, and aquaculture: A review. Smart Agric Technol 2023;3(July 2022):100105. http://dx.doi.org/10.1016/j.atech.2022.100105.

[16] Nguyen A, Windfeld E, Francis M, Lhermie G, Kim K. A virtual farm tour for public education about dairy industry. In: Proceedings of the IEEE conference on virtual reality and 3D user interfaces abstracts and workshops (VRW). 2023, p. 438–41. http://dx.doi.org/10.1109/VRW58643.2023.00095.

[17] Ippolito PM. How government policies shape the food and nutrition information environment1the views expressed in this paper are those of the author and do not necessarily represent the views of the federal trade commission.1. Food Policy 1999;24(2):295–306. http://dx.doi.org/10.1016/S0306-9192(99)00025-1.

[18] Allen S, Goddard E, Farmer A. How knowledge, attitudes, and beliefs impact dairy anit-consumption. Br Food J 2018;120.

[19] Clément C. To market to market: Exploring distribution models in nova scotia. 2015, https://foodarc.ca/wp-content/uploads/2015/03/To-Market-to-Market-Distribution-Models-Jan-2015.pdf. [Accessed 2023-09-07].

[20] Rubio-Tamayo JL, Gertrudix Barrio M, García García F. Immersive environments and virtual reality: Systematic review and advances in communication, interaction and simulation. Multimodal Technol Interact 2017;1(4). http://dx.doi.org/10.3390/mti1040021.

[21] Radianti J, Majchrzak TA, Fromm J, Wohlgenannt I. A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. Comput Educ 2020;147:103778. http://dx.doi.org/10.1016/j.compedu.2019.103778.

[22] Hamilton D, McKechnie J, Edgerton E, Wilson C. Immersive virtual reality as a pedagogical tool in education: A systematic literature review of quantitative learning outcomes and experimental design. J Comput Educ 2021;8(1):1–32. http://dx.doi.org/10.1007/s40692-020-00169-2.

[23] Allison D, Hodges L. Virtual reality for education? In: Proceedings of ACM symposium on virtual reality software and technology. 2000, p. 160–5. http://dx.doi.org/10.1145/502390.502420.

[24] Tarng W, Chang M-Y, Ou K-L, Yu K-F, Hsieh K-R. The development of a virtual farm for applications in elementary science education. Int J Distance Educ Technol 2012;10.

[25] Lampropoulos G, Keramopoulos E, Diamantaras K, Evangelidis G. Augmented reality and virtual reality in education: Public perspectives, sentiments, attitudes, and discourses, Vol. 12. MDPI; 2022.

[26] Yu F, Zhang J-F, Zhao Y, Zhao J-C, Tan C, Luan R-P. The research and application of virtual reality (VR) technology in agriculture science. In: International conference on computer and computing technologies in agriculture. 2009, p. 546–50.

[27] Ye S, Yang Y, Meng L, Li G, Wang Z, Zhao H. Applications of teaching based on virtual reality in agro-pastoralism areas. JICTE 2023.

[28] Jimenez IAC, Violante LCGMG, Marcolin F, Vezzetti E. Commonly used external TAM variables in e-learning, agriculture and virtual reality applications. MDPI; 2020.

[29] Urem F, Goleš IK, Beljo I. Education for entrepreneurship in agriculture - results of the agrient project implementation. In: International convention on information, communication and electronic technology. 2021, p. 532–6.

[30] Schütz A, Kurz K, Busch G. Virtual farm tours—Virtual reality glasses and tablets are suitable tools to provide insights into pig husbandry. PLoS One 2022.

[31] Chateau H, Delsart M. Virtual visits of pig farms in times of COVID-19, a feedback. 2021, https://www.vet-alfort.fr/images/actus/2021-09-30_-_AG_AEEEV/Pr%C3%A9sentation_AEEEV_V2_HC_compressed.pdf. [Accessed 2023-09-12].

[32] Wynn DC, Eckert CM. Perspectives on iteration in design and development. Res Eng Des 2016;28(2):153–84. http://dx.doi.org/10.1007/s00163-016-0226-3.

[33] Ericson JD. Mapping the relationship between critical thinking and design thinking. J Knowl Econ 2021;13(1):406–29. http://dx.doi.org/10.1007/s13132-021-00733-w.

[34] Mumtaz M, Ahmad N, Ashraf MU, Alghamdi AM, Bahaddad AA, Almarhabi KA. Iteration causes, impact, and timing in software development lifecycle: An SLR. IEEE Access 2022;10:65355–75. http://dx.doi.org/10.1109/ACCESS.2022.3182703.

[35] Gonzalez-Franco M, Ofek E, Pan Y, Antley A, Steed A, Spanlang B, Maselli A, Banakou D, Pelechano N, Orts-Escolano S, Orvalho V, Trutoiu L, Wojcik M, Sanchez-Vives MV, Bailenson J, Slater M, Lanier J. The rocketbox library and the utility of freely available rigged avatars. Front Virtual Real 2020;1(561558):1–23. http://dx.doi.org/10.3389/frvir.2020.561558.

[36] Brooke J. SUS - a quick and dirty usability scale. In: Usability evaluation in industry. 1996, p. 189–94.

[37] Sauro J, Lewis JR. Quantifying the user experience: practical statistics for user research. Morgan Kaufmann; 2012.

[38] Davis S, Nesbitt K, Nalivaiko E. A systematic review of cybersickness. In: Proceedings of the 2014 conference on interactive entertainment. 2014, p. 1–9. http://dx.doi.org/10.1145/2677758.2677780.

[39] Bendigeri C, Devaraj E. Advances in design and manufacturing of VR headset. In: Metaverse and immersive technologies. Wiley; 2023, p. 191–216. http://dx.doi.org/10.1002/9781394177165.ch7.

[40] Hallström J. Embodying the past, designing the future: Technological determinism reconsidered in technology education. Int J Technol Des Educ 2020;32(1):17–31. http://dx.doi.org/10.1007/s10798-020-09600-2.

[41] Ahn SJG, Bailenson JN, Park D. Short- and long-term effects of embodied experiences in immersive virtual environments on environmental locus of control and behavior. Comput Hum Behav 2014;39:235–45. http://dx.doi.org/10.1016/j.chb.2014.07.025.

[42] Li J, Vinayagamoorthy V, Williamson J, Shamma DA, Cesar P. Social VR: A new medium for remote communication and collaboration. In: Extended abstracts of the 2021 CHI conference on human factors in computing systems. 2021, http://dx.doi.org/10.1145/3411763.3441346.